The Effect of Coordinated Movement on Infant Vocalizations

B058231

20,603

MSc by Research Psychology

The University of Edinburgh

2015

Abstract

This study was designed to examine the effect of coordinated motor movement on infant vocalizations. Sixteen infants aged 9-18 months were videotaped in a semi structured play session. Results indicated that babbles were more likely to be produced in coordination with motor movement than without. Babbles that were produced in coordination with motor movements were found to be longer and more diverse than babbles that were uncoordinated with movement. Motor-vocal coordination in infants displayed similar temporal patterns to that observed in the adult gesture-speech system. No right hand bias was observed in infant's manual motor movement.

Introduction

Gestures are the meaningful hand and arm movements we make while speaking (McNeill, 1992). Gesturing can take many forms and there are a wide variety of theories on what purpose they serve in our communication. The main types of gestures that are widely researched are representational gestures, deictic gestures, beats, and conventional gestures. Representational gestures, sometimes called iconic or lexical gestures, are meaningful arm and hand movements that look like the referent either literally or metaphorically (McNeill, 1992). The classification of metaphoric gestures, which are a particular type of iconic gesture, also exists, although most researchers use the overarching category of representational gesture to include both iconic and metaphorical. For example, a classic representational gesture would be bringing both hands together to form a heart shape when speaking about either a heart or love. Deictic gestures refer to particular spatial locations, such as pointing to give directions, or to indicate an object or location of focus. Beats, while not as investigated as the other gesture forms, are seemingly random arm and hand movements used to place emphasis on certain elements of speech. As a result of their random nature, far less research has been done on beats and the potential purpose they may serve. McNeill (1992) specifically emphasizes that beats are a form of non-imagistic gesture, as they do not present a discernable meaning. Conventional gestures, also referred to as emblems, are conventionalized and cultural signals and include things such as a thumb up to indicate, “Okay”. Emblems are distinct from other forms of gesture in that they contain meaning in and of themselves and do not require concurrent speech to successfully deliver semantic information (Willems & Hagoort, 2007).

In McNeill’s paper Hand and Mind: What gesture reveals about thought (1992; see also McNeill, 2000), four major characteristics of adult gesture and speech co-production are outlined. Firstly, gesture and speech convey information simultaneously within a single utterance. Information provided by gesture is often complementary rather than identical to the information provided in speech, but both are presented in a simultaneous manner bound within a single utterance. Another major characteristic is that gesture primarily consists of arm, hand, and finger movements. While infants and occasionally children have a tendency to involve their whole body in gesture, it is uncommon to observe adults gesturing in a non-manual fashion or in ways involving the lower half of the frame. Additionally, when looking at a right-handed population, the majority of gestures consist of right hand movements. There is also a significant tendency for gestures to be unimanual (Iverson and Fagan, 2004; Kimura 1973a, 1973b). The final characteristic presented by McNeill (1992) is the observation that gesture and speech are tightly linked in time, with gestures produced either slightly before or concurrently with speech. It is from this point that many researchers have posited a form of collaboration between the gesture and speech systems, with both functioning together as a simultaneous communicative device.

Gestures are thought to be a universal feature of human communication and appear to be produced by all speakers across cultures, although some cultural differences in gesture have been observed (Iverson & Thelen, 1999). Italian culture is considered to be an especially high gesture culture (Barzini, 1964; see also Kendon, 1992), while other cultures, such as English, are considered to be relatively low gesture cultures (Graham & Argyle, 1975). Differences in gesture rates have also been observed in bilingual populations. Pika, Nicoladis, and Marentette (2006) found that English/Spanish and French/English bilingual adults had a higher gesture rate in English than did English monolingual adults. Specifically, both bilingual groups used more iconic gestures when communicating in English than the English monolinguals. Researchers are divided as to the reasoning behind the observed differences in gesture rate. Some researchers believe that people are more likely to produce a higher number of gestures in their weaker language, as gestures are thought to aid in accessing words and phrases that might be more difficult to do successfully when communicating in a second language (Krauss & Hadar, 1999). In contrast, others predict that gesture rate will be higher when a bilingual is speaking their stronger language, as it is there that they will be attempting to convey more complex messages, which many believe are facilitated through the use of gesture (Nicoladis, Mayberry & Genesse, 1999). That being said, the research on gesturing in bilingual populations is varied, and little conclusions have been confidently drawn to date (Nicoladis, 2007).

Research indicates that the adult gesture system is a complex and multifaceted tool for communication. Alongside language, nonverbal postures, and other communication strategies, gesture enriches our communicative abilities, and often aids in the efficient delivery of our intended messages. The adult gesture system has seen much research over the past few years and many attempts have been made to unpack the intricacies of our gesture output and the purpose our gestures serve. Research on gesture is varied, with some believing that gesture serves to aid the listener, by providing the listener with additional visual information regarding the referent (Beattie & Shovelton, 1999). In contrast, others believe that gesture primarily functions to aid the speaker, such as by helping the speaker access words and phrases (Krauss, 1998). Gesture has additionally been found to help increase verbal fluency (Rauscher, Krauss, & Chen, 1996), and high gesture rates are also associated with more complex storytelling in both children and adult populations (Colletta, 2009; Colletta, Pelleng & Guidetti, 2010). As such, it has been suggested that the primary beneficiary of gestures are the speakers themselves rather than their interlocutor (Krauss & Hadar, 1999; Krauss, Dushay, Chen & Rauscher, 1995).

In addition to providing information to the listener and helping the speaker in their communication, gestures often serve to support linguistic communication, as is the case where gesture provides referential content such as visually displaying size or location (Gullberg, De Bot & Volterra, 2008). Additionally, researchers have found that listeners are readily able to discern information presented solely through gesture (Alibali, Flevares, and Goldin-Meadow, 1997). This however has not always been observed, as some researchers suggest that people do not always recognize the intended meaning of gestures when the accompanying speech is not present (Krauss, Morrel-Samuels & Colasante, 1991).

Nevertheless, gestures appear to be a consistent component of human communication, appearing across cultures and remaining temporally linked with speech across a variety of languages and contexts. Gestures are consistently tightly timed with speech (McNeill, 1992), and are produced even by blind speakers who are speaking to blind listeners (Iverson & Goldin-Meadow, 1998). Iverson & Goldin-Meadow (1998) videotaped participants naturally responding to a series of reasoning tasks that have been known to elicit gestures. It was found that blind speakers gestured at a similar rate to sighted speakers, and that both blind and sighted speakers gestured even when their listener was blind and unable to perceive any of the gestures produced. Evidence of gesturing in blind populations suggests that there is an intrinsic link between gesture and speech that goes beyond the boundaries of visual communication. In fact, many theories on gesture believe that they play an importation role in, not only the delivery of speech, but also the formation of speech itself.

In a similar vein of research to studies involving blind speakers and listeners, gesture has also been observed in contexts with varied interlocutor visibility. Bavelas, Chovil, Lawrie & Wade, (1992) found that gesture rate remained consistent regardless of interlocutor visibility, while other studies have found gesture rate to increase when speakers are able to see their interlocutor (Alibali, Heath & Myers, 2001). Alibali et al., (2001) found that representational gesture rate increased when speakers were able to see their listeners, but that gestures continued to be produced even in conditions where the speaker was unable to see their listener. From this, Alibali and colleagues suggested that gestures might serve both a communication function and a “speaker-internal” function (Alibali et al, 2001). Similarly, Bavelas, Kenwood, Johnson & Phillips (2002), found that gesture rate would even increase if speakers believed that someone would see a videotape of them speaking later on, and suggested that this may be indicative of the speaker increasing their gesture rate in an attempt to ameliorate their communication. Although the research is varied, it appears as though people will often gesture even when they are unable to see their listener. From that, it has been argued that gestures may not be solely for the benefit of the listener, but may in fact play a role in the language production and output of the speaker (Alibali, Kita & Young, 2000).

Despite varying views on the function of gestures, as gesture and speech appear to be profoundly linked much research has suggested that they are an inter-connected system (Goldin-Meadow & Singer, 2003). In fact, the connections between speech and gesture appear so profound that some have suggested that what we refer to as the spoken language system should be renamed to the more encompassing “speech-gesture system" (McNeill, 1992). Consequently, we must turn to the current leading theories on gesture in order to have a more comprehensive understanding of the interplay between gesture and speech and the consequences of such links.

Gesture Theories

To date, numerous researchers have developed theories on the function and development of gestures. These theories are distinct from one another by way of how they view the importance of gesture but all are modelled on the adult language system, as no theory to date has been developed to fully account for gestural systems in children. Here we outline five leading theories on gesture; the lexical retrieval hypothesis, the information-packaging hypothesis, the growth point theory, the interface hypothesis, and the lexical semantics hypothesis. These theories are by no means the only theories on gesture but they are certainly the most cited and examined in the current research community.

The lexical retrieval hypothesis argues that there are specific links between gesture and speech that occur at a particular moment during speech production (see Krauss, 1998; Rauscher, Krauss, & Chen, 1996). Specifically, the lexical retrieval hypothesis posits that gesture occurs at the phonological encoding stage, with gestures playing an important role in aiding the formation of an utterance. According to their theory, when lexical retrieval is difficult, speakers naturally rely on gesture. Researchers argue that gestures incorporate the spatio-dynamic features of a concept and as such, by performing a gesture that mirrors certain aspects of the spatio-dynamic features of the concept in question, it helps to activate the concept in memory. Once the concept has been activated in memory it then leads to a successful vocalization of the word being retrieved (Krauss, Chen & Gottesman, 2000). In other words, gesture is directly aiding in lexical retrieval by facilitating access to particular concepts through the mirroring of specific spatio-dynamic features. As outlined in the theory, the connections between speech and gesture are limited and exist only at a distinct point in the production of speech. Activation between the two facets of the system works only in the direction of gesture influencing speech, with gestures reflecting representations of concepts in working memory and thus serving an active role in lexical access.

A series of experiments by Krauss et al., (1995) found that visual access to a speaker, and subsequently their gestures, did not enhance or facilitate their communication to a listener. Using a controlled referential communication task, participants were asked to listen to their partner's descriptions and decide if the description was that of an abstract graphic design, a novel synthesized sound, or kinds of tea. For some participants they communicated with their partner face to face, some had access to both a video and sound recording of their partner's descriptions, and for others they solely had access to the sound recording of the description. Krauss and colleagues found that accuracy was better than chance in all conditions but did not improve when the participants had any form of visual access to their partner. Specifically, the participants in the face-to-face condition and the video recording condition did not have a higher rate of success than the participants who only had access to the sound recording of the descriptions. The researchers argued that as a result of the fact that there was no improvement in the task during the conditions that provided interlocutor visibility, gestures were functioning only to aid the speaker in lexical retrieval and not in facilitating the communication of the descriptions. In other words, gestures were aiding the speaker but not having any profound effect on the listener. From this, Krauss and colleagues (1995) suggested that it was evidence for the lexical retrieval hypothesis, and that gesture was serving to facilitate speech production through "motoric representations of some of the concepts expressed in speech" (p. 548).

Another theory on gesture is the information-packaging hypothesis, which posits that gesture is involved in the conceptual planning of speech (Alibali et al., 2000). According to this theory, gesture is serving to help speakers "package" information in preparation for speech (Alibali et al., 2000). In this context, packaging refers to how we organize information in such a way that it can be linguistically expressed. Specifically, Alibali and colleagues state that "speakers use gesture to explore alternative ways of encoding and organizing spatial and perceptual information" (p.595, Alibali et al., 2000). While the lexical retrieval hypothesis argues for a minimal role of gesture in speech, the information-packing hypothesis argues that gesture is actually heavily involved in the conceptualization process. From this theory it follows that gesture plays a role in thinking, and some researchers have put forth the hypothesis that gesture may influence other cognitive processes as well such as memory (Alibali et al., 2000). While the lexical retrieval hypothesis argues that gesture plays a role in the formation of surface forms of utterances, the information-packaging hypothesis argues that gesture is involved in the conceptual planning of the messages.

To put the information-packaging hypothesis to the test against the lexical retrieval hypothesis, Alibali et al., (2000) used two tasks that required similar lexical access but different forms of information packaging. Five-year-old participants completed a Piagetian conversion task (Piaget, 1967), followed by a basic description task where they had to describe how two objects differed in appearance. The Piagetian task involved children having to judge whether two equal quantities remained the same after being transferred in some manner. For example, children were presented with two glasses of water of equal size and quantity. One of the glasses of water was then transferred into a bowl and the children were asked to judge whether the quantities of the water remained the same. In addition, children were also asked to explain the reasoning behind their judgments. In a second task, children were asked to describe how the two items, for example a glass of water and water in a bowl, were different.

Under the lexical retrieval hypothesis, the gestures of children in both conditions should not vary, as gestures will be aiding the children in the formation of utterances. In comparison, under the information-packaging hypothesis, the differences in the conceptualization within both tasks will elicit varied gestures. Specifically, Alibali and colleagues (2000) predicted that children would produce more representational and information rich gestures representing physical properties of the objects in the explanation task than in the description task. The researchers defined information rich, or non-redundant gestures, as deictic gestures that incorporated a “representational element” (p.598). These non-redundant gestures were of particular interest due to the popular observation that children often relay some information solely in speech and some solely through gesture when doing conversion or similarly based tasks (Church & Goldin-Meadow, 1986). What they found was exactly what they predicted, with children producing similar utterances across conditions but producing more information rich gestures during the conversion task. Researchers subsequently concluded that this was evidence for the information-packaging hypothesis and further support for the idea that gestures function beyond lexical retrieval. They argued that "the action of gesturing helps speakers to organize spatial information for verbalization, and in this way, gesture plays a role in conceptualizing the message to be verbalized" (p. 610).

Both the lexical retrieval and the information-packaging hypothesis view gesture as being secondary to speech in communication. They are viewed as overlapping but distinct systems, wherein gesture serves a supporting role in the formation of utterances. In contrast, the growth point theory and interface hypothesis see gestures as an integral part of an utterance (Gullberg et al., 2008).

The growth point theory views gesture as indicative of thought itself; that gesture is a different form of symbol to language, but that both simultaneously come together to form a thought (McNeill, 1992; McNeill, 2005). According to McNeill (1992), a growth point is "the smallest unit of the imagery-language dialectic". A growth point is the intersection where the organization of linguistic and imagistic content occurs. According to the theory, imagistic thinking and linguistic thinking come together in the formation of utterances, with the outcome of imagistic thinking being gesture and the output of linguistic thinking being speech. For example, if someone were to say, "it fell down" while simultaneously gesturing in a downwards-thrusting motion, the growth point would be the combination of both the linguistic and the imagistic output. The idea of "it fell down" exists in both the language mode and the gesture mode, and the growth point involves the combination of the linguistic fragment and the imagistic output in the form of a gesture (McNeill, 1992). According to McNeill and Duncan (1998), "we use the gesture's semantic content and its synchrony (that is, the synchrony of the gesture stroke phase) with speech to infer the growth point" (p.3).

Evidence supporting the growth point theory can be seen in instances where the gestures and the accompanying speech are forcibly separated. Owing to the fact that, under the growth point theory, gesture and language are a tight combination, dysfluencies in one mode can cause similar dysfluencies in the paired output. For example, it has been found that when speakers experience periods of stuttering their gestures are momentarily disrupted, beginning only once speech has begun again (Mayberry & Jaques, 2000). Additionally, it has been found that listeners who are presented with some information through speech and some information through gesture, are unable, after a short delay, to recall which information was presented through which modality (McNeill, Cassell & McCullough, 1994). From this line of evidence researchers have argued that it is indicative that "the meaningful linkage of gesture and language resists division" (p.4, McNeill & Duncan, 1998).

Another theory, which holds that gesture is an integral part of an utterance, is the interface hypothesis. The interface hypothesis posits that gestures originate from an interface representation of a referent and are specifically designed for speaking (Kita & Ozyurek, 2003). According to Kita and Ozyurek (2003), an interface representation is " the spatio-motoric representation (i.e., information about action and spatial information represented in terms of action) that is organized for the purpose of speaking" (p. 17). Under this theory, gestures encode non-linguistic properties of a referent while also structuring the information about the referent in a way that is linguistically expressible. As such, under the interface hypothesis, gesture is directly influenced by the already existing restrictions present in linguistic expressions. Gestures are thus created based on the interface representations of all possibly accessible linguistic expressions and the particular spatio-motoric properties possessed by the referent (Ozyurek, 2010).

Kita and Ozyurek (2003) used a cross linguistic comparison to test the interface hypothesis. According to the interface hypothesis, gestures surrounding a particular event will differ in similar ways to the manner in which the information for the same event was represented in the distinct languages. As gestures are dependent on what is linguistically expressible, then the gestures accompanying a particular referent will vary depending on what is expressible in the co-produced speech. Kita and Ozyurek (2003) compared speakers of American English, Turkish, and Japanese by having them describe the events that took place in a short nonverbal cartoon. A particular event in the cartoon, where one character uses a rope swing to move locations, was noteworthy, as English is the only language in which there is a word, "swing", to describe both the change in location and the arch shaped trajectory of the action. Hence, the linguistic packaging of information regarding the swing event is posited to be different in the English speakers when compared to the Turkish and Japanese speakers. From this, the researchers predicted that the gestures produced by the English speakers would differ from those produced by both the Turkish and Japanese speakers. Results confirmed their hypothesis and the gestures produced by the English speakers differed from both the Turkish and Japanese speakers. Specifically, the gestures produced by English speakers conveyed both the change in location and the arching motion of the action, while the gestures of the Turkish and Japanese participants conveyed only the change in location. As the English speakers had a lexical expression to describe both the change in location and the arch direction simultaneously, their gesture subsequently reflected both actions. Comparatively, the Japanese and Turkish speakers' gestures only conveyed the change in location as their respective languages did not have a linguistic expression that could successfully package both actions. The researchers argued that this demonstrates a direct connection between the linguistic representation of information and the gestural representation of the event.

The final and additional gesture theory we will discuss is the lexical semantics theory. Under this theory, it is argued that gestures are generated from the lexical semantics in the accompanying speech. Gestures do not encode new information, but rather encode only what is already encoded in the accompanying speech (Butterworth & Hadar, 1989). Unlike the previous theories mentioned above, gestures are not seen as having an effect on speech production. Instead, gestures are viewed as being compensatory, only being used when speech is interrupted. For example, gestures are often seen in situations of coughing, or when the speaker is unable to find the right word. In these cases, gestures appear to help the speaker continue communication when speech is interrupted and to retrieve the appropriate word when experiencing a dysfluency in speech. It is important to note that numerous researchers are critical of the lexical semantics theory, as there is clear evidence of situations in which information is encoded solely through gesture (Alibali, Flevares & Goldin-Meadow, 1997).

Although each gesture theory is distinct, there is much overlap between them. Both the lexical retrieval hypothesis and the information-packaging hypothesis propose that gestures have an important role in speech formation. Comparatively, both the growth point and the interface hypothesis suggest that gestures have a more profound influence on the formation of the linguistic output. Regardless of their differences, the main theories of gesture outlined above all concur that gesture is co-expressed with speech and that it plays a critical role in shaping our communications. Evidently there is an important and multifaceted connection between our verbal and non-verbal communication and there is much evidence to suggest that gesture and speech are intrinsically connected. Regardless of the details of the particular theories, all agree that there is an observable and seemingly intrinsic link between speech and gesture that requires further exploration. This link between the motor system's output of gesture and the vocal system's output of speech appears profound, and to understand the depths of the connections between the systems we must turn to the developmental and neurophysiological evidence for potential linkages between the two distinct systems.

Developmental Origins

In comparison to adult gesture, far less research has been done to explore the world of gesture in children and infant populations. This is understandable, as children and infants are still rapidly developing and it becomes challenging to unpack the particular functions that gestures are serving at distinct points throughout development. Nevertheless, research examining gestures in infants and children is undertaken, with each study helping to shed light on the developmental beginnings of the adult gesture-speech system.

As gestures are produced in conjunction with speech, preverbal infants do not display gestures in the same fashion as those produced by adults. While adult gesture can be divided into relatively clear and defined categories depending on the adjoining referent, infant gesture is considered in a much broader sense. In fact, infant gesture research undertakes a much more inclusive approach, and tends to include any instances of motor movement coordinated with vocalizations in their explorations of the connections between the two systems (Iverson & Fagan 2004; Ejiri & Masataka, 2001). By using a broader inclusion criterion, it allows researchers more opportunities to examine the two systems without being restricted by the inclusion of only clearly defined gestures, such as the deictic pointing gesture. Under this research paradigm, when considering infant vocal and motor output, many instances of overlap between the two systems are found (Iverson & Fagan, 2004).

In point of fact, the interconnectivity between motor output and verbal output, in the form of general vocalizations or language, is readily observable, which then begs the question of when and how this connectivity arises. Throughout development there is an observable interplay between motor movement and vocalizations but it appears as though there are even more elementary connections between the hands and mouth. Such evidence for connections between the motor and vocal system can be immediately seen after birth in the Babkin reflex. The Babkin reflex consists of an infant opening their mouth when pressure is placed on the palms of their hands (Babkin, 1960; Butterworth & Hopkins, 1988) and is argued to be one of the earliest examples of connections between the hands and mouth. Right from the beginning it appears as though infants are inclined to link their hands to their mouths, often using the mouth as a means of exploring and interacting with their environment (Rochat, 1989). Fogel and Hannan (1985) observed early infant-mother interactions and found that particular infant gestures, specifically one finger pointing, were associated with higher levels of vocalizations or movements of the mouth. Infants are also observed to instinctually open their mouth when bringing their hands to their face (Butterworth & Hopkins, 1988). Taken together, this evidence points to profound and rudimentary connections between the oral and manual systems that are present from the earliest stages after birth.

At around six to eight months, infants begin to display emerging control over their vocal and motor systems (Iverson & Thelen 1999). It is at this point that we begin to observe more directed vocalizations including cooing and the beginning of reduplicated babbling. Reduplicated babbles are vocalizations consisting of syllable repetition, such as “bababa” or “gagaga” (Iverson, Hall, Nickel & Wozniak, 2007).

While babbles are not the first vocalizations produced by infants, reduplicated babbling is seen as an important milestone in infant language development as it marks the first occasion of the production of a long string of well-formed syllables (Fagan, 2005). On a motor system front, it is at this point in development that we begin to see the earliest stages of rhythmic movement. According to Thelen (1981), rhythmicity is evidence of emerging control over a particular system. Hand banging and waving, along with reaching and pointing are thus posited to be indicative of the infants' emerging control over their motor system. It is also at this point in development that there is an occasional coordination between the two systems, with activity in both the manual and vocal systems occurring in a temporally synched manner (Iverson & Thelen, 1999). There also appears to be a close synchronicity between the emergence of the rhythmic vocal action of reduplicated babbling and the rhythmic motor action of hand banging with both appearing around the 27-week mark (Oller & Eilers, 1988).

It is worth noting that the connection between motor action and babbling appears to be quite profound. One study by Mastataka (2001) examined babble onset and early first word forms, along with hand banging and other motor behaviours, in infants with Williams syndrome. Williams syndrome is a rare genetic disorder affecting the bodies' ability to produce elastic properties in the arteries, lungs, intestine and skin (Masataka, 2001). It is characterized by mental retardation and a variety of cognitive deficits including speech and language difficulties. In his study, Masataka (2001) compared babble and first word onset with a variety of motor milestones including rhythmic hand banging. Although all infants included in the analysis displayed developmental delays in both motor and linguistic activities, the onset of hand banging was found to be a reliable predictor of the onset of canonical babbling. Masataka thus suggested that the hand banging acts as a "control parameter for production of canonical syllables" (p.163).

Locke, Bekken, Mcminnlarson & Wein (1995), studied prebabbling and babbling infants to further examine the emergence of babbling and any corresponding changes in motor rhythmicity. Sixty-one infants were seen immediately prior to the beginning of babbling and at various intervals after the onset of babbling. Researchers used a series of silent and noise making rattles, placed in either the left or right hand, to observe the control over vocal and motor behaviour in babbling and prebabbling infants. Results indicated that the audibility of the rattle did not significantly affect the rate of shaking, in that infants displayed a similar rate of rattling regardless of whether the rattle was noisy or silent. In contrast, the rate of babbling was most strongly influenced by age and consequently level of babbling. Specifically, the older babbling infants displayed a significantly higher rate of shaking than the prebabblers, regardless of the audibility condition. Moreover, there was a right hand bias in the older babbling infants that was not present in the younger prebabbling group. Locke and colleagues concluded that this might be evidence for an emerging left hemisphere bias. Specifically, Locke et al. suggested that babble onset may be indicative of more advanced control over the left hemisphere, supported by the observation that both repetitive right hand activity and repetitive vocal activity develop at similar timelines. It is important to note that Locke and colleagues regarded babbling as evidence for an infant's increasing control over the motor movements involved in the vocal system. Specifically, Locke et al. (1995) suggested that similar trajectories between the onset of reduplicated babbling and the appearance of a right hand bias is indicative of the brain's increasing specialization for language functions.

As babbles consist of syllables, which are fundamental linguistic units, it is considered by many to be a primarily linguistic output (Pettito, Holowka, Sergio, Levy & Ostry, 2004). Furthermore, a high degree of continuity has been observed between the babbling patterns of a specific child and their later early word forms, which some suggests is evidence for babbling as a linguistic precursor to speech (Vihman, 1996; Iverson et al., 2007). It has been proposed that babbling is evidence for infant's sensitivity to language rhythms and that, under the linguistic view of babbling, reduplicated babbles are examples of a rudimentary language system (Iverson et al., 2007). Additional evidence, in support of the linguistic view of babbling can be seen in infant hand preference such as those observed by Locke et al. (1995) as mentioned previously. In his original study, Ramsay (1984) also found that infants displayed a right hand preference and suggested that the synchrony between the appearance of the hand preference and the onset of reduplicated babbling may be evidence for an increase in specialization across brain hemispheres. Ramsay (1984) argued that this proposed shift at the time of babbling to left-lateralized motor activity is evidence that babble onset is controlled by language specific mechanisms (see also Iverson et al., 2007). Further evidence for babbling as a linguistic behaviour lies in the observed developmental delays. Specifically, research has found delayed or abnormal infant babbling to be a reliable predictor of delayed language onset. In a longitudinal study by Lynch, Oller, Steffens & Levine (1995), babbling patterns of typically developing infants and infants with Down's syndrome were compared, with results indicating that infants with Down's syndrome had delayed babble onset followed by delayed language onset. Lynch and colleagues thus proposed that a late babble onset is directly related to a later language onset.

The connection between early babbling behaviour and later speech development is suggested to be so profound that many researchers are now proposing that the onset of canonical babbling may provide the basis for a screening procedure for language dysfunction. This screening procedure would potentially allow for early diagnosis of children at risk for later language and speech disorders (Oller, Eilers, Neal & Schwartz, 1999). Owing to the fact that the onset of canonical babbling occurs within a specific time frame for the vast majority of infants, approximately six months, a parent reported screening procedure is suggested to be a reliable predictor of dysfunctional babble development (Oller et al., 1999).

Babbling is also seen across infant populations, further suggesting that it is a consistent developmental milestone. Pettito and Marentette (1991) observed deaf infants born into homes with sign language. They found that, rather than displaying normal verbal babbling behaviour, the infants appeared to move their hands in particular, rhythmic ways and concluded that they were performing a form of "manual" babbling. As the observed hand movements were not meaningful and did not appear communicative, Pettito and Marentette proposed that they were not gestures in the classical sense but rather they were a manifestation of the deaf infants' early babbling. They concluded that these manual babbles were evidence for an internal and inherent language system that infants are sensitive to. That being said, Meier and Willerman (1995) observed manual babbling in a sample of hearing infants who concurrently displayed typical verbal babbling behaviour. As such, they suggested that manual babbling might be an example of an infant rhythmic motor behaviour as opposed to evidence for babbling as a linguistic behaviour.

Similarly to Meier and Willerman (1995), many researchers have suggested that babbling is not a purely linguistic act but rather is indicative of a developing motor system. In the motor stereotypy view suggested by Kent (1984), reduplicated babbling is just one of many rhythmically organized motor behaviours observed in infants. In similar fashion to the waving of arms as a precursor to crawling, babbling is seen as a rhythmic motor stereotypy that begins with basic mandibular oscillation (MacNeilage & Davis, 1993). Increases in babble complexity are thus explained as a result of the infant developing more precise control over the tongue, jaw, and throat, which allows them to develop a more diverse syllabic repertoire (MacNeilage & Davis, 2000). To test the idea of babbling as motor stereotypy, MacNeilage and Davis (2000) compared the babble patterns of infants raised in English environments to those of infants raised in other language environments, namely French, Swedish, Japanese, Ecuadorian-Quichua, and Brazilian-Portuguese. By comparing infants with different language environments, MacNeilage and Davis proposed that any similarities in infant babbling would be indicative of babbling as a developing motor behaviour rather than a linguistic output. They found that all infants, regardless of their language environment, displayed similar patterns of organizational syllabic babbling. In this case, MacNeilage and Davis (2000) specified that the physical properties of the syllables produced by infants were universal and appeared across cultural groups. From this, MacNeilage and Davis (2000) concluded that there is a universal pattern of babbling that is dependent on the particular properties of the jaw rather than the linguistic conditions surrounding the infant.

Although seemingly in contrast with one another, it is completely plausible that both the linguistic view of babbling and the motor stereotypy view of babbling could be simultaneously correct. Perhaps babbling begins as a basic rhythmic motor behaviour, later developing into an early linguistic form as it becomes more complex. Similarly, it could be that the early manual movements coordinated with vocal output made by infants develop into the more complex and information rich gestures we observe in adult speakers. The developmental trajectories of both babbling to speech and movement to gesture could be produced together to increase mastery over both the vocal and motor systems concurrently. Iverson et al. (2007) did a study to examine the conflicting theories of babbling as motor stereotypy and babbling as a linguistic behaviour. Using the experimental design set forth by Locke et al. (1995), Iverson and colleagues used noise making and silent rattles to investigate the relationship between reduplicated babble onset and the previously reported observable increase in right-handed manual activity. Unlike the cross sectional design used by Locke et al. (1995), Iverson and colleagues produced a longitudinal account of infant motor and vocal development. Data on twenty-six infants was collected at three points in their development; just prior to babble onset, at babble onset, and just following babble onset. As in the design used by Locke et al. (1995), infants were presented with two visually identical rattles, one being silent and one producing noise. Rate of rattle shaking was measured for each infant at each of the three developmental points.

Similarly to Locke et al. (1995), Iverson and colleagues found an increase in rattle shaking from the pre-babble to babble onset points. However, unlike Locke et al. (1995) the observed increase in rattle shaking did not show any evidence of a right hand bias. Moreover, they did not find any evidence of hand preference nor did they observe any interaction between hand preference and increases in rhythmic manual motor activity. From this, Iverson et al. (2007) argued that their data does not support the proposed shift in hemispheric specialization occurring at babble onset and consequently, does not support the argument that an emerging left hemisphere bias is indicative of the linguistic view of babbling.

Instead, Iverson et al. (2007) argue that by asking whether babbling is either a motor skill or a language skill, we enshroud the possibility that babbling may in fact be a far richer developmental undertaking. Iverson and colleagues argue that both views on babbling may be correct and that babbling may begin as a rudimentary mandibular oscillation and later develop into a more complex linguistic event. Iverson and colleagues maintain that once infants have mastered their developing speech and motor control, they are then able to explore more profound and language specific sounds (Iverson et al., 2007). This effect can be seen in what is known as "babbling drift" wherein later vocalizations produced by older infants increasingly begin to mirror the sounds specific to their language environment (De Boysson-Bardies, Sagard & Durand, 1984). Iverson et al. (2007) further proposes that the feedback received by infants can also help shape their babbles into more linguistic events. As babbles transform from basic mandibular oscillations into more complex mouth movements, parents are sensitive to the change and may shift their responses and interpretations of their infant's vocalizations (Goldstein & West, 1999). From this line of evidence, Iverson proposes that babbling is too complex to be reduced to either a linguistic or a motor event and instead should be considered as existing as both.

In children, gesture has often been found to be a reliable indicator of language development and mastery. Capirci, Iverson, Pizzuto & Volterra, (1996) found single gestures and gesture-word combinations produced at 16 months of age to be significantly correlated with total vocal production at 20 months. In addition, other studies have found similar results wherein the presence of gesture speech combinations predicts the onset of two word combinations, suggesting that gesture is playing some sort of role in advancing linguistic development (Butcher & Goldin-Meadow, 2000). It has also been found that children with more object gestures tend to have larger vocabularies and reach the first ten-word milestone earlier than children with fewer object gestures in their repertoire (Bates, Bretherton, & Snyder, 1988). Additionally, at around 11 to 13 months a significant correlation between comprehended words and number of action gestures produced has been observed (Fenson et al., 1994). There is also an observed increase in the amount of deictic gestures, such as pointing, used by infants from the 16 to 20 month point (Iverson, Capirci & Caselli, 1994). Researchers suggest that this phenomenon is specifically indicative of gesture playing an important role in acquiring language, as pointing is an intrinsic tool in establishing moments of joint attention (Iverson et al., 1994).

As gesture is intimately linked with language, preverbal children and infants are not able to display gesture in the classic sense and as such, little research exists on the nature of gesture and nonverbal communication in this population. Nevertheless, some researchers have attempted to investigate the broad gesture systems of children, along with the more general developmental trajectories of the motor and vocal systems that appear simultaneous. This connection between the motor and vocal systems can be seen throughout the lifespan beginning with the early Babkin reflex and resulting in the complex and multifaceted gestures produced by adult speakers. These early observable connections between the systems suggest that there is a profound bond between the two that may go beyond what we are capable of perceiving. Therefore, we must turn to neuropsychological evidence to better understand the basic underpinnings connecting both the motor and the vocal system.

Neuropsychological evidence for a linked system

Connections between the vocal and motor systems can be seen across various modalities and there exists a substantial amount of neuropsychological evidence for links between both systems (Iverson & Thelen, 1999). Iverson and Thelen (1999) review four main lines of research exploring the neuropsychological connections between language and movement. The first link between the two is that there are common brain mechanisms shared between both systems. Through the use of electrical mapping studies, areas of the brain required for both language and sequential movement have been identified. The lateral perisylvian cortex of the dominant hemisphere, specifically the posterior end of the inferior frontal gyrus and various sites across the perisylvian cortex are found to produce disturbances in both language and motor functions when stimulated (Ojemann, 1984). Taken together, this evidence suggests that there may be a common mechanism underlying both language and sequential motor tasks (Iverson &Thelen, 1999). Ojemann (1984) suggested that the common underlying mechanism might be that of precise timing, as it is required for the production of small and precise movements necessary for both successful language production and sequential movements.

The other lines of research exploring the neuropsychological links between language and movement involve patterns of activation across brain mechanisms. Specifically, research has found that activation in the motor areas of the brain often occurs during language specific tasks that do not involve any direct motor production or planning. Pullvermüller, Preissl, Lutzenberger & Birbaumer (1996), found activation in the motor cortex when participants were asked to silently read words. Other studies have found the cerebellum to be activated during a word association task, suggesting some form of intricate connection between the cerebellum and the more formal language areas of the brain such as Broca's area (Petersen, Fox, Posner, Mintun & Raichle, 1989). Leiner, Leiner & Dow (1989; see also Leiner et al., 1993) found additional anatomical evidence of connections between the cerebellum and Broca's area. Specifically, they found anatomical evidence for a pathway connecting the cerebellum and frontal lobe via the thalamus. Within this pathway exist connections between the cerebellar regions and the areas of the brain commonly associated with language processes (Leiner et al., 1989).

Further evidence for potential neuronal connections between motor and vocal systems can be found in a study done by Gentilucci (2003). In his experiment, Gentilucci had participants pronounce syllables while grasping a variety of objects. When participants were asked to grasp larger objects, they had a larger lip aperture and produced louder syllables than when they were asked to grasp smaller objects. This result was also found to be present when participants were observing others performing the grasping of various objects. Gentilucci (2003) had participants pronounce a variety of syllables while watching others grasping objects of differing sizes. Mirroring the previous effect, lip aperture and syllable volume were found to be larger and louder when the participants were observing people grasping larger objects. On that account, Gentilucci (2003) suggests that this is indicative of linkages between hand and mouth gestures and evidence for potential common neuronal locations.

Various transcranial magnetic stimulation studies have found that activation of the hand motor cortex increases during reading and spontaneous speech (Meister, Boroojerdi, Foltys, Sparing, Huber & Töpper, 2003; Syeal, Mull, Bhullar, Ahmad & Gage, 1999). Interestingly, no similar language related effect has been found in the leg motor area, suggesting that the connections between manual movement and language may be at a neuronal level and more profound than connections between the language areas and other motor areas of the brain. As noted by Rizzolatti and Craighero (2004), the observed activation is limited to the left hemisphere, eliminating the possibility that the increase in excitability is due to the motor movements involved in word articulation. Various transcranial magnetic stimulation studies have found activation in areas of the motor cortex when participants are listening to speech sounds

(Sundara, Namasivayam & Chen, 2001). Other fMRI studies have found activation in the premotor cortex when presented with action words but not object words (Kable, Kan, Wilson, Thompson-Schill & Chatterjee, 2005). Tettanti and colleagues (2005) presented participants with sentences such as "I bit an apple" and "I appreciate sincerity". The sentences involving clear action saw increased brain activation in the left inferior frontal cortex compared to the abstract sentences. Finally, a study by Aziz-Zadeh, Wilson, Rizzolatti and Iacoboni (2006) found activation in premotor areas when participants were presented with action sentences. Interestingly, premotor activation was contextually dependent on the content of the sentences. In other words, the exact location of the activation was contingent on the type of action presented in the sentence. For example, action sentences involving the foot would activate the premotor areas responsible for foot movements. Similarly mirrored patterns of activation were found for sentences involving mouth actions and hand actions (Aziz-Zadeh et al., 2006).

Other research has gone in the exact opposite direction and found that areas of the brain commonly associated with language are activated when people engage in motor planning (Krams, Rushworth, Deiber, Frackowiak & Passingham, 1998). Researchers have observed activation in Broca's area during motor tasks, specifically during tasks involving hand movement and finger tapping (Erhard et al., 1996). A positron emission tomography study by Krams et al (1998) examined cerebral blood flow in participants during a task where they were required to copy hand movements. In conditions where there was a delay prior to the execution of the copied hand movement, there was an observed increase in blood flow to Broca's area, specifically Brodmann's area 44. Similarly, in a condition involving motor planning and no actual execution of the hand movement there was an observed increase in blood flow to Broca's area. Taken together this evidence, as suggested by Iverson and Thelen (1999), puts forth the idea that Broca's area, along with other brain mechanisms discussed previously, may be involved in the precise coordination and timing required in speech and gesture.

The final line of neurophysiological evidence for links between the motor and vocal systems involves the similar patterns of breakdown observed in both systems.

Patients with Broca's aphasia exhibit parallel patterns of dysfunction across language and motor modalities (Iverson & Thelen, 1999). Patients with Broca's aphasia tend to rely on more open class words and have deficits involving the connecting elements of language, such as articles and prepositions. Similarly, these patients are found to have high levels of iconic gestures and few of the fluid beat gestures that serve to accompany speech (Pedelty, 1987). Both grammatical functors and beats are used to increase the fluidity of communication and similar deficits in both are argued to be evidence of paralleled dysfunction across the motor and vocal systems (Iverson & Thelen, 1999).

Hill (1998) investigated the potential overlap in motor and language difficulties in a study comparing children with specific language impairment (SLI) and children with developmental coordination disorder (DCD). Seventy-two children between the ages of 5 and 13 were included in the study and were divided into four groups; children with SLI, children with DCD, age matched controls, and younger controls. Participants completed a battery of neuropsychological tests designed to assess language skill and movement capabilities. Participants were then asked to copy unfamiliar postures and movement sequences similar to those used in a previous study (Kimura et al, 1973a, 1973b). Postures consisted of unfamiliar and meaningless hand postures and sequences of hand postures. Participants were also asked to demonstrate a series of transitive and non-transitive representational gestures. Examples of these include miming the act of brushing your teeth, which is transitive, and waving goodbye, which is non-transitive. Interestingly, results showed that a significant number of children with SLI displayed a similar performance as the children with DCD on the motor tasks. Moreover, children with SLI scored worse than children with DCD and age matched peers on the representational gesture task (Hill, 1998). This evidence suggests that there are similar deficits in both the vocal and motor systems, and that children with SLI appear to possess previously unexamined motor deficiencies that may be directly linked to their language impairments. In fact, numerous studies have found that children with language impairments also exhibit difficulties with motor movements, specifically limb coordination (see Hill 2001 for a review).

Some neuropsychology studies have also begun to specifically explore the neurological underpinnings of gesture. Kelly, Kravitz, and Hopkins (2004) used an event-related potential experiment to explore the neurological activation caused by the gestures accompanying speech. Participants viewed people making a gesture that was related to the physical properties of a referent, such as indicating the height or the width of an object. These gestures were preceded by sentences that were either congruent with the following gesture or incongruent. Compared to when the gesture and preceding sentence were congruent, when the gesture was preceded by an anomalous sentence, an N400 effect was observed, indicating that the anomalous pairing was harder to process. Kelly, Ward, Creigh & Bartolotti (2007), replicated this finding and also found an N400 effect produced in the context of incongruent gesture. In a similar study, the N400 effect was also found when participants were shown a video of a short cartoon, followed by a video of people gesturing in a way that either matched the preceding cartoon or was anomalous (Wu & Coulson, 2005). As before, the N400 effect was observed when the gesture was incongruent with the other information provided, in this case the cartoon. Finally, in a study by Skipper, Goldin-Meadow, Nusbaum & Small (2007), participants watched an actor tell a story either without any hand movements, with gesture, or with person adjusting hand movements such as touching their glasses or scratching their body. They found that in the gesture condition, Broca's area exerted less influence on other neural areas than compared to the no movement or person adjusting hand movement conditions. They concluded that this was indicative of less effort being required by Broca's area. They argued that gestures serve as an additional source of information and aid the listener in understanding the message, to the point that less semantic control is required for successful comprehension (Skipper et al., 2007).

Iverson and Thelen's Coupled Motor-Vocal Theory

Taking together the neuropsychological evidence for linkages between the motor and vocal areas of the brain, and the temporally linked developmental time lines for the two systems, Iverson and Thelen proposed a theory of a coupled speech-gesture system (1999). In the context of a dynamic systems approach wherein the mouth and hand are separated but interconnected systems right from birth, Iverson and Thelen argue that "the systems activating mouth and arms can mutually influence and entrain one another [...] these entrainments are dynamic and flexible such that activation of one system can have various effects on the other" (p.28). They propose that it is through this particular linkage of systems that we see the adult gesture-speech system emerge. Four concepts are outlined as being key to the proposed coupled motor-vocal system. These concepts, outlined individually below, include coupled oscillators, entrainment, elicitation thresholds, and relative activation strengths.

Neuromotor systems that are under impaired voluntary control are found to oscillate naturally (Iverson & Fagan, 2004). This can be seen in the rhythmic and repetitive limb movements produced early on by infants. Such rudimentary oscillations include rhythmic movements such as shaking, kicking, waving, arm and leg banging, and rocking among others. MacNeilage and Davis (2000) argued that such oscillations can also be seen in the vocal production system. Namely, they suggested that reduplicated babbling was an example of increasingly controlled mandibular oscillations. Under their view, an increase in the production and variability of reduplicated babbles is evidence of an infant's increased control over movements of the tongue, throat and jaw (MacNeilage & Davis, 2000).

As oscillations can be seen in both the vocal and motor system, through mandibular oscillations and rhythmic limb movements respectively, it follows that there may be entrainment between the two systems. Entrainment occurs when the particular rhythmicity of one system causes another system to fall into a distinct pattern of synchronization. Iverson and Thelen (1999) argue that entrainment can be seen in the vocal and motor systems, causing them to mutually influence one another to produce vocal and motor outputs that are temporally linked. They propose that the entrainment between the two systems is dynamic and flexible, with entrainment producing linkages that can be either tightly temporally linked or simply overlapping in time.

Following entrainment, the next key concept in Iverson and Thelen's (1999) proposed model of a coupled motor vocal system is that of elicitation thresholds. The threshold of an activity regards the ease with which the activity is performed.

Activities with a low threshold appear often and in a variety of differing contexts. In comparison, activities with a high threshold appear less often and in a more restricted set of contexts. Thresholds are lowered only with the repeated practice of an activity. For example, an infant's threshold for speech is initially very high, with only a few words being produced in very restricted contexts. With repeated practice, the threshold for speech becomes lower and the infant is able to produce a wider variety of words and in a larger amount of contexts.

Related to elicitation thresholds is the notion of activation strengths, the final concept outlined by Iverson and Thelen's proposed motor-vocal system (1999). Activation strength is the strength of an activity once it's threshold has been reached. Novel activities have a low activation strength, while well practiced and often performed activities have a high activation strength. In the example of infant's speech outlined previously, a low activation strength can be seen in the initial instances of infant speech. As producing speech when it is a novel activity requires a considerable amount of effort, the initial activation strength of speech is considered to be lower. Once it becomes a well established and more practiced activity to the infant, it is considered to have a higher activation strength.

It is important to note that Iverson and Thelen highlight the fact that in order for entrainment to occur, high levels of activation are required. As such, only familiar and well-learned behaviours within systems have the ability for mutual entrainment. By their model, when activation in one system is stable and well practiced, its activation can extend to an adjoining system leading to a coupled model. For example, if an infant is performing an intense motor activity, such as vigorous arm waving, that activation can leak into the coupled vocal system and manifest itself as a coordinated vocalization (Iverson and Thelen, 1999). They present the idea that "it is possible that production of repetitive, rhythmically organized movements gradually entrains vocal activity, leading eventually to the production of the mandibular oscillations that comprise babbling" (p.33).

As mentioned previously, numerous studies have found connections between infant vocalizations and motor rhythmicity (Iverson & Fagan 2004, Ejiri & Mastaka 1999). Iverson and Thelen (1999) suggest that such evidence is indicative of entrainment between the systems and that the two systems may in fact aid in each other's development.

Iverson and Fagan (2004)

Iverson and Fagan (2004) did a comprehensive study with infants in an attempt to test the 1999 model of the proposed development of the gesture-speech system (Iverson & Thelen, 1999). By looking at the instances of coordination between the rhythmic manual movements and vocalizations produced by infants, Iverson and Fagan provided insight into the potential early beginnings of the adult speech and gesture system. Iverson and Fagan aimed to collect a descriptive analysis of the vocal and motor output of infants. Specifically, they hoped to examine the frequency of vocal-motor coordination in the outputs produced by infants, and to compare the rate of coordination for vocal coordination with manual movements with the rate of vocal coordination with non-manual movements. They also proposed to examine the laterality of the movements produced by infants to see if infants followed the movement pattern of adults, whereby right unimanual movements are more commonly produced than manual movements involving both arms. Finally, Iverson and Fagan aimed to provide descriptive information regarding the timing of infants' movements. In particular, they focused on whether instances of coordination between the vocal and motor system were movement initiated, vocalization initiated, or synchronous, wherein both movement and vocalizations appearing simultaneously.

Following the theory set forth by Iverson and Thelen (1999), Iverson and Fagan predicted three outcomes from their study. Firstly, they predicted that vocalizations produced by infants that were coordinated with rhythmic movement should likely be rhythmic themselves. As the coupled motor-vocal system relies on the concept of entrainment, then it follows that rhythmicity should be observed in both outputs of the systems involved. Secondly, they predicted that babbles should be more likely to be coordinated with manual rather than non-manual movements. If the infant vocal-motor system is a precursor to the adult gesture-speech system, as theorized by Iverson and Thelen (1999), then it follows that any coordination between the vocalizations and movements produced by infants should follow a similar pattern to those observed in the adult system. As most gestures produced by adults involve manual rather than non-manual movements, then accordingly the researchers argued that we should observe the same pattern in infants. Finally, Iverson and Fagan predicted that coordinated vocalizations and rhythmic manual movements should be higher for babblers than prebabblers. They argued that this increase in coordination amongst the babblers would be seen as a direct result of the system of entrainment between the motor and vocal system put forth by Iverson and Thelen (1999).

Forty-seven infants between the ages of 6 to 9 months were observed in a semi structured play session with their primary caregiver. Forty-two infants identified as babblers were included in the final analysis. Infants were observed for a 25-minute semi structured play session that involved two fixed order conditions; play with rattles and play with toys. Play with rattles involved a series of three different rattles, while play with toys involved a series of four toys set by the researcher. Sessions were videotaped and later coded for both rhythmic limb movements and vocalizations. Rhythmic limb movements were defined as movements repeated in the same form at least 3 times, and included arm, leg, and head movements. The temporal boundaries for vocalizations were determined by an audible breath or by a silence lasting 1second or longer. After an initial round of coding for vocalizations and babbles, a second round of coding was done to include transcripts of the vocalizations. Consonant vowel, or CV, repetitions were defined as utterances containing at least two repeated syllables. CV repetitions were used for analysis as they are considered to be inherently rhythmic at a within utterance level, as the rhythmic jaw movement necessary to generate CV repetitions displays similar features to other rhythmic motor behaviour (see Davis & MacNeilage, 1995, MacNeilage & Davis, 1993).

For an event to be coded as a vocalization and rhythmic movement coordination, it required some degree of temporal overlap. Instances of one behaviour occurring during an ongoing bout of another behaviour, and instances of both behaviours beginning simultaneously were both included. Analysis was only done on utterances consisting of at least two repetitions, meaning that only canonical or reduplicated babbling was included and any marginal babble was excluded.

In regards to their descriptive analysis of the vocal and motor output of infants, Iverson and Fagan produced clear information regarding the coordination patterns between the two systems. Results from the Iverson and Fagan (2004) study found that approximately 20% of all rhythmic movements were coordinated with vocalizations. This result was found to be stable across the age of the infants. Additionally, the rate of motor-vocal coordination, which was determined by the total number of coordinated movements divided by time, was higher for manual rather than non-manual movements. This result was also found to be stable across infant age. Additionally, they found that the coordination between vocalizations and motor movements was observed in both rattle and play conditions, suggesting that this observation is a consistent phenomenon and not contextually dependent. Single and right arm movements were also found to be more common than left manual movements, which again mirrors the adult gesture pattern observed in right handed speakers (Kimura, 1973a). They also found that "the vast majority of infants' vocal-motor coordination bouts were either movement initiated or synchronous" (p.1060) (Iverson & Fagan, 2004). This observation mirrors the patterns observed in the adult gesture system whereby the great majority of adults' gestures either slightly precede or co-occur with their accompanying speech. Iverson and Fagan (2004) also found that older infants, aged 8 to 9 months, coordinated vocalizations and motor movements at a higher rate than younger infants, aged 6 to 7 months, but only in the rattles context.

With respect to their theory driven predictions based on Iverson and Thelen's (1999) model, Iverson and Fagan (2004) found that CV repetitions were more likely to occur with rhythmic movement than without. Secondly, the researchers found that babblers had a higher proportion of vocalizations coordinated with rhythmic manual movements than the prebabblers. Finally, the researchers found that CV repetitions were significantly more likely to be coordinated with rhythmic manual movements than with rhythmic non-manual movements.

While Iverson and Fagan (2004) observed an age related increase in coordination between motor and vocal behaviours, another study by Ejiri and Masataka (2001) found the exact opposite effect. Ejiri and Masataka's (2001) longitudinal study is one of the only other attempts to investigate the potential motor-vocal coordination in infants. Four infants were studied longitudinally from 6 to 11 months. Each infant was observed and videotaped for 1.5 hours every month and a sample of 40 minutes for each month for each infant was extracted and analyzed for vocalizations and motor actions. Vocalizations and motor movements were considered coordinated if they temporally overlapped for a minimum of 1 second.

Ejiri and Masataka (2001) found that a higher percentage of vocalizations co-occurred with rhythmic movements than with other motor behaviours. Motor movements included activities such as mouthing, banging, manipulating, and rhythmic actions. Results also indicated that infants were more likely to display a higher volume of rhythmic movements around the onset of canonical babbling. Similarly to the Iverson and Fagan study (2004), a larger amount of vocalizations co-occurred with rhythmic movements than not. As mentioned previously, Ejiri and Masataka also found that there was an age related decrease in rhythmic actions, which was in direct contrast to the age related increase found by Iverson and Fagan (2004).

Iverson and Fagan (2004) suggested that the observed differences in both studies were possibly due to methodological differences. While Ejiri and Masataka (2001) defined coordination as an overlap of at least 1 second, Iverson and Fagan included any instance of overlap as evidence for a coordinated event. Moreover, Ejiri and Masataka (2001) did not specify which limbs were involved in rhythmic motor movement, nor the context within which the movement took place. As a result of these methodological differences, Iverson and Fagan (2004) suggested that the different observations made by the two studies could be due to the disparate coding criterion. Regardless of the differences in methodology and results, both studies observed coordinated rhythmic motor and vocal events in infants, serving as supporting evidence for the coupled motor-vocal system proposed by Iverson (1999). Building upon the work done by Iverson and Fagan (2004), we aim to further explore the potential relationship between the vocal and motor systems in infants, and any potential overlap that may be present.

Current study

Babbling infants are to be observed in a semi structured play session designed to elicit and encourage babbling and motor movement. Rates of coordination between vocalizations and movement will then be assessed, with a focus on the rate of coordination between reduplicated babbling and movements. We predict that babbles will be more likely to occur with movement than without. Specifically, we predict that coordination between the vocal and motor systems will primarily involve manual movements, in a similar pattern to the adult gesture system. We also predict that babbles coordinated with movement will be longer, potentially caused by possible entrainment from the motor system, and the subsequently increased activation. In a similar manner, we predict that babbles coordinated with movement will also be more diverse and include a larger number of different syllables. We will also examine instances of syllable transition within the coordinated babbles, along with the exact timing of the coordination. If the infant vocal and motor systems are entrained as suggested by Iverson and Thelen (1999) then we should observe a difference in the babbles produced with movement and those produced without. Moreover, if the movements produced by infants alongside vocalizations are indicative of an early gesture-speech system, then it follows that they should display similar characteristics to the mature adult gesture-speech system. Namely, infants should favor right unimanual movements when coordinating their movements with vocalizations. Additionally, coordination between the vocal and motor outputs should be movement initiated or synchronous.

Pilot Study

Participants

To begin, an initial pilot study involving three infants (M=13 months, SD=0), was conducted. Two females and one male infant were included in the analysis and all were the result of normal, full term pregnancies. Infants had been recruited across the greater Edinburgh area through word of mouth and advertisements in social media and local parenting groups. All families received a small gift as a form of honorarium for their participation. Two of the three infants had older siblings while the male infant was an only child.

Procedure

Data was collected in the infant's home wherein the researcher and the infant's primary caregiver were included in a semi structured play session with the infant. Approximately 45 minutes of semi structured play was recorded for each infant over the course of a single session. Primary caregivers were encouraged to interact with infants in ways that they themselves deemed natural and stimulating for the child. Recording was to stop at any point where the infant became distressed, although this did not occur and as a result, recording was continuous for all infants included in the pilot study.

Materials

For the pilot study, no outside materials were used. Children interacted with their primary caregiver in their home environment, and thus were surrounded by personal toys and belongings. Outside equipment consisted solely of a video camera and a tripod used by the researcher for data capture.

Coding

All recorded data was then uploaded into ELAN language software, whereby a cursory coding procedure took place. Videos were initially coded for vocalizations and babbles produced by the infant. Instances of vocalizations and babbles were time stamped, and a transcript was included for all babbles. At this stage of coding researchers did not have visual access to the video, to ensure that the coding was acutely focused on the noises produced by the infant. Vocalizations were coded as babbles if they involved at least one syllable repetition, such as "ba ba". No distinction was made between reduplicated babble and variegated babble, with reduplicated babbling being the repetition of the same syllable and variegated babble involving the repetition of differently sounding syllables. From this we can argue that the vocalizations coded as babbles in our study can be considered canonical babbling by the guidelines set forth by Oller (1980). All other vocalizations produced were coded as general vocalizations, with the exception of any biological and vegetative sounds produced by the infant, which were not included in analysis. Biological sounds included things such as crying or laughing while vegetative sounds included behaviours such as coughing or burping.

A second round of coding was completed, focusing on the movements produced by the infant. At this stage of the coding procedure the researcher did not have auditory access to the video to ensure that the only focus was on the movements produced by the infant. Movements were separated according to the limb used to produce the movement, and the coding resulted in categories for both arm and leg movements. Each coded movement included a small summary detailing the type of movement and which limb, or combination of limbs, was involved in the process. Movements of the head, neck, and torso were not coded and subsequently our analysis only included movements made by the arms and legs. A third "Other" category was created and included any movements produced by the infant that were not distinct limb movements. This included events such as crawling, walking, and being moved by their caregiver.

A third round of coding was done to analyze moments of overlap between the vocalizations and movements of the infant. Any instances of overlap between the vocal and motor output were classified as coordinated events, and divided into distinct groups specifying the limbs and type of vocalization, babble or general, that was involved. Coordination was considered to occur if there was any form of overlap between the vocal and motor output. In other words, if the movement of the infant overlapped with their vocalization or babble at any point, it was classified as an instance of coordination. This is a similar criterion to that used by Iverson and Fagan (2004). Initially, any instances of coordination between hand movements and babbles were coded. This was followed by the coding of any instances of coordination between leg movements and babbles. Similarly, any coordination between general vocalizations and hand movements was coded, along with any coordination of general vocalizations and leg movements.

Analysis

To begin analysis we examined the babbles produced by the infants and whether or not they were more likely to be coordinated with movement. Analysis showed that of the coded babbles, 55% of them were coordinated with hand movement, 25% of them were coded with leg movement, and 20% were uncoordinated. Infants produced coordinated hand movements and vocalizations at a rate of 0.4336/minute, and had an average rate of coordinated leg movement and vocalizations of 0.3181/minute. This means that infants produced a hand movement that was coordinated with some form of vocal output, either babble or general vocalization, at a rate of 0.4336 coordinated events for every minute. Similarly, infants produced a leg movement that was coordinated with vocal output at a rate of 0.3181 coordinated events for every minute. The average rate of hand movements were determined by dividing the total number /minute of hand movements by time. The average rate of leg movements was determined in a similar fashion.

When we unpacked this rate further we found a more distinct difference between manual and non-manual coordination. Namely, the average rate of coordinated babbles and hand movements was 0.6508/minute while the average rate of coordinated babbles with leg movements was 0.1905/minute. This means that infants produced approximately 0.65 babbles coordinated with manual movements every minute, and approximately 0.19 babbles coordinated with leg movements every minute. The average rate of coordinated vocalizations with hand movements was 0.7501/minute and the average rate of coordinated vocalizations with leg movements was 0.1004/minute. The results from the pilot study indicated that babbles were more likely to appear in coordination with movement than without. Bearing in mind the theory put forth by Iverson and Thelen (1999) that proposes a system of entrainment between the vocal and motor systems, our observed connection between babbles and coordinated motor events offers support for their theory. Results also indicated that there was a higher rate of coordinated hand movements with babbles than of leg movements with babbles. As adult gesture consists primarily of right hand unimanual movements (Kimura, 1973a; Kimura 1973b), it appears as though infants' preference for coordination between manual movements and vocal output directly mirrors the mature adult gesture-speech system. From these results it appeared as though there was some form of connection between the vocal and motor output produced by infants that merited further investigation. Subsequently, we decided to pursue a more comprehensive experiment to further examine these apparent connections.

We used a semi structured play session, as per the pilot study, to record infants interacting with their primary caregivers. Included in the experiment was the addition of an experimental condition designed to increase infant motor output. From this, we coded all motor and vocal outputs produced by the infants under observation. We then compared babbles coordinated with movement to the babbles that were uncoordinated with movement to see if the produced babbles differed in length, diversity, type token ratio, and location of syllable transitions.

Method

Participants

Sixteen infants, eight boys and eight girls, were recruited through word of mouth, and advertisements through local baby groups and social media. All infants were between the ages of 9 and 18 months (M=11.85 months, SD=2.24) and the result of normal, non-complicated pregnancies and birth. All testing took place in Canada and Scotland, five of the infants were born and tested in Edmonton, Canada while the remaining eleven participants were born and tested in Edinburgh, Scotland. Twelve of the infants came from monolingual homes, while four were growing up in a consistently bilingual environment. Bilingual environments were English/Polish, English/German and English/Italian. All the infants tested in Canada had exposure to French, although none of the parents classified themselves or their home as an English/French bilingual environment. Three of the infants had older siblings, with no infant having more than one sibling total. Infants were all of Caucasian descent. Parent reported babbling history showed that the infants began babbling on average at 6.09 months (SD=1.48). Parents had an average of 16.69 years of education (SD=1.45) and all infants were from two parent homes. All infants were included in the final analysis.

Materials

In the experimental conditions, small bells were attached to either the infants' wrists or ankles. As previous studies have shown that infants increase their motor output in a context in which they are able to produce noise, such as through the use of noise-making rattles, the condition of the bells was designed with the goal of increasing the infants' motor output (see Locke et al., 1995). Before beginning the experiment, a small observational study was conducted to determine the most effective bell to include in the experiment. Three infants aged 9 months were presented with a series of four bells. Each bell was attached to the infants' wrists and ankles as per the format in the experimental condition, and the length of time each infant played comfortably with a caregiver, without removing the bell, was recorded.

The bell that the infants allowed on for the longest duration of time was used in the later experiment. The bells were approximately 1 cm in diameter and connected to a soft ribbon that allowed for easy attachment and detachment to the infant's limb.

Procedure

Infants and primary caregivers were videotaped for a total of 35 minutes in a semi structured play session. Observations were done in the home of the infant, at a time where the primary caregiver suggested the infant would be most alert. Parents were instructed to play with their infant as they would normally, and that the observation would be terminated at the end of the allotted time, unless otherwise specified by the parent. All data was collected in a single session. The parents were provided with an introduction to the study and consent forms detailing the format and procedure of the study. Demographics were collected regarding the birthing history, presence of siblings, parental education and employment, and babbling history. The parent provided all demographic information through self-report.

Observations were divided into three sessions, one lasting fifteen minutes that acted as a control condition, followed by two ten-minute sessions involving an experimental manipulation. The experimental manipulation consisted of the addition of a bell attached to the wrist or ankle of the infant, depending on whether it was the hand or leg condition.

The first fifteen-minute session consisted of free play between the parent and infant. This session was always recorded first and served as a control condition wherein the infant could become comfortable with the presence of the researcher and the video camera. The following two ten-minute sessions consisted of an experimental manipulation involving either the hand or the leg of the infant. In the hand condition, a small bell was attached to the wrist of the infant. Once the bell was secure and the infant appeared comfortable, play would resume for ten minutes. In the leg condition, the same bell was attached to the ankle of the infant. As before, once the bell was secure and the infant appeared comfortable with the change, play would resume for ten minutes. The order of the hand and leg bell conditions was counterbalanced, as was whether or not the bell was placed on the infant's left or right side. Infants were observed in a variety of positions including walking, sitting upright, prone, supine, on hands and knees, rocking, and crawling. All positions were adopted naturally by the infant with minimal movement of the infant by the caregiver.

After the three observational sessions had been successfully completed, the parents were given a debriefing form regarding the nature of the study, along with a small gift as a token of appreciation for their participation. Collected data was then imported into iMovie and all files were transferred to a QuickTime format. Videos were then uploaded into ELAN language software for subsequent coding and analysis.

Coding of infant vocal output

Data was initially coded for general vocalizations and babbles, with the same criteria as that used in the pilot study mentioned above. To ensure effective coding, the researcher did not have visual access to the footage at this time. Any noise made by the infant was coded as a babble if it included a clear syllable repetition. As a syllable repetition was required for inclusion in the babble category, any instances of infants producing a single syllable were regarded as general vocalizations. This is a similar inclusion criteria to those used by Iverson and Fagan (2004) (see also Oller, 2000). Both reduplicated babbles and variegated babbles were included as per before, meaning both a repeated stream of the same syllable and a repeated stream of differing syllables were coded as babbles. Each individual babble was time stamped and transcribed so the exact script of the babble could later be analyzed. Using a similar criteria to Iverson and Fagan (2004), boundaries for babbles were determined by an audible breath made by the infant, or an observed silence lasting 1 millisecond or longer (see also Locke et al., 1995). Any other noise made by the infant was coded as a general vocalization, excluding biological and vegetative sounds. Biological sounds included such things as laughing and crying, while vegetative sounds involved behaviours such as coughing or burping. Neither biological nor vegetative sounds were included in any of the analysis, which is considered to be standard practice for infant language studies (Iverson & Fagan 2004, see also Nathani & Oller, 2001). General vocalizations were defined by identical boundaries as babbles, 1milisecond of silence or a produced audible breathe, and were also time stamped in ELAN.

Coding of infant motor output

Following the coding of all the sounds produced by the infants, the researcher then coded the videos for any instances of movement. At this stage of the coding process there was no access to the auditory component of the video. All movement produced by the infant was coded, with the exception of movements involving only the head or neck. As the focus of our study was on the leg and arm movements of infants, only movements involving the limbs of the infant were analyzed. The onset of the movement was defined by the first instance of a limb extension, and the offset of the movement was defined by the moment the motion of the movement ceased. Hand movements included any instances where the infant moved their arms, wrists or hands. Such movements were time stamped and within the coding it specified which arm, right, left, or both, was involved in the movement. A brief summary detailing the nature of each movement was also included. For example, some common summaries of movement include "left arm reaches forward", " both arms bang rhythmically", and "right arm extends outward". Leg movements included any instances where the infant moved their leg, excluding walking and crawling. As per the hand movements, leg movements were coded following a similar structure. All leg movements were time stamped and included a short summary detailing the nature of the movement and specifying the specific leg involved. Examples of such summaries include "both legs kick" and "right leg extends outwards".

Instances of crawling and walking were coded separately from leg and arm movements, as we wanted to focus our analysis on instances of distinct and novel movements produced by the infant. Crawling and walking were coded in the same fashion as the arm and leg movement categories and included a time stamp. They did not include any coding for the exact limb involved, nor did they include a summary of the movement. Any other movement produced by the infant was included in an "Other" category. This included any instances where the infant was moved or carried by the caregiver. The coding for walking, crawling and other movements were not included in the subsequent analysis.

Coding of coordinated motor-vocal events

A third round of coding was then done to examine any instances of coordination between the sound and movement produced by the infant. At this point in the analysis, the researcher had access to both the visual and auditory components of the video. This round of coding resulted in four separate categories of coding. The first was any instances of coordination between a babble and a hand movement. Data was included in this category if the time stamp of a babble overlapped at any point with the time stamp of a hand movement. The overlap did not have to last for the entire duration of the babble but rather any instance of overlap between the babble and movement was included. The second category was any instances of coordination between a babble and a leg movement. This followed the same criteria used for the coordination between hand movements and babbles, whereby any instance of overlap between the vocal and motor output was classified as a coordination event. The third and forth categories involved coordination between general vocalizations and hand movements and general vocalizations and leg movements accordingly. These categories followed the same criteria as before, where any instance of overlap between the vocal and motor output was considered to fulfil the criterion of inclusion into the category.

At this stage we had 11 distinct categories coded for each video. These were

1. Babbles
2. General vocalizations
3. Hand movements
4. Leg movements
5. Crawling
6. Walking
7. Other
8. Coordinated babbles with hand movement
9. Coordinated babbles with leg movement
10. Coordinated general vocalizations with hand movement
11. Coordinated general vocalizations with leg movement

This coding was done for all participants across all three conditions. All data was then subsequently exported into Excel for further analysis.

Coding of babbles

To begin, the transcriptions of all babbles were further broken down and coded. Babbles were separated across participants and conditions (No bell, bell on arm, bell on leg) and transcribed. The length and diversity of each babble was then determined using the transcriptions coded previously. The total number of syllables included in the babble determined the length of the babble, and the total number of different syllables in the babble determined diversity. The coordination for each babble was also included and specified whether the babble was coordinated with no movement, hand movement or leg movement. If the babble was coordinated with movement we also specified if it was by the right, left, or both limbs. We also specified whether the coordination was movement initiated, synchronous, or voice initiated. An event was classified as movement initiated if the motor output of the infant preceded the coordinated babble. Synchronous events involved instances of coordination wherein the babbles and the motor movement appeared simultaneously, and coordination that began with the babble preceding the start of the movement were classified as voice initiated. Additionally, for each babble we included a measure of syllable transition, specifying the location of any change in syllable. If a babble included a single repeated syllable, such as “da da da” it was coded as “no transition”. In similar fashion, if a babble contained a syllable transition at the edge of the babble, for example “ma ma da”, then it was coded as “Edge”. Finally, if a babble contained a syllable transition in the centre of the babble, for example “da ma da”, it was coded as “Centre”.

An average length of babble, which was the average number of syllables included in each babble, was created for each participant. Additionally, an average diversity of babble, which was a measure of the number of different syllables in each babble, was also produced. The averages produced included all babbles produced by each participant in each of the three conditions. A type token ratio was also created for each participant in each condition, and was a measure of the ratio of the diversity of babble to the length of babble. The type token ratio was determined by dividing the number of different syllables by the total number of syllables. The type token ratio was included to ensure that an observed higher level of diversity in a babble was not merely due to an increase in length. As a longer babble has a higher chance of containing a larger variation of syllables, simply because of it's extended length, the type token ratio was used to provide a more accurate representation of the data.

Results

In our study, we aimed to closely examine the relationship between infant babbling and motor movement. Specifically, we endeavoured to investigate if babbles coordinated with movement displayed differing characteristics to babbles that were uncoordinated with any form of movement. With this goal in mind, we examined the length of uncoordinated babbles with coordinated babbles, along with the diversity of uncoordinated and coordinated babbles. We also compared type token ratios between uncoordinated and coordinated babbles. We then looked at syllable transitions to compare the number and location of syllable transitions in uncoordinated and coordinated babbles. Finally, we analyzed the laterality and timing of infant coordination between vocal and motor outputs. Specifically, we examined if there was any evidence of a right hand bias among infant movements and if coordination events were movement initiated, synchronous, or voice initiated. It is with these directions of analysis in mind that we present our results thusly.

General vocal and motor output

On average, infants produced a mean of 104.19 general vocalizations across all three conditions (SD=46.50), with an average of 69.57 general vocalizations being coordinated with a hand movement (SD=34.49) and approximately16.88 general vocalizations being coordinated with a leg movement (SD=11.20). As general vocalizations were not the primary focus of this study, all subsequent analysis focused on the relationship between babbles and movement, and general vocalizations were excluded from further analysis.

On average, each infant produced approximately 27.81 babbles across all three conditions (SD=21.99), along with approximately 378.88 hand movements (SD=117.06) and 100.31 leg movements (SD=72.07). Of the 27.81 babbles produced, 1.62 of them were uncoordinated with movement (SD=3.32), 19.62 were coordinated with hand movement (SD=15.10), and 6.56 were coordinated with leg movement (SD=7.50). On average, each babble was approximately 3.33 syllables long (SD=1.14) and had an average diversity of 2.21 syllables (SD=0.35). The average type token ratio across conditions and participants was 0.71 with a standard deviation of 0.16.

Effect of experimental manipulation

The first analysis focused on our experimental manipulation of the addition of bells on the arms and legs. Unfortunately, this did not have a strong effect and did not serve to increase the movement rate as was expected. Infants in the control condition had a babble rate of 0.93 babbles/minute (SD=0.94), moved their hands at a rate of approximately 10.72 movements/minute (SD=4.02), and moved their legs at a rate of approximately 2.58 movements/minute (SD=2.50). In comparison, in the hand condition where the bells were placed on the infants' wrists, infants babbled at a rate of 0.68 babbles/minute (SD=0.57). When in the hand condition, infants' rate of moving their hands was approximately 10.68 movements/minute (SD=5.11), while their rate of moving their legs was approximately 3 movements/minute (SD=2.58). In the leg condition where the bell was placed on the legs of the infants, infants displayed a babble rate of 0.71 babbles/minute (SD=0.59). In the same condition, infants had an average rate of moving their hands of 11.14 movements/minute (SD=3.09), and an average rate of moving their legs of 3.16 movements/minute (SD=2.24). Our experimental manipulation did not serve to produce a strong effect and the addition of the bells saw no real changes, increase or otherwise, in the rate of movement of the infants. As such, we collapsed these three conditions for all subsequent analyses.

While no major differences in the length and complexity of babbles was noted in experimental conditions, such differences did emerge when the coordination of babbles was examined more closely. Information regarding the length and diversity of uncoordinated babbles, babbles coordinated with hand movements, and babbles coordinated with leg movements can be seen in Graphs 1, 2, and 3 respectively.

Babble length

The average length of uncoordinated babbles was 1.45 syllables (SD=1.57). In comparison, the average length of babbles coordinated with hand movements was 3.25 syllables (SD=1.40). For babbles coordinated with leg movements they were an average of 2.68 syllables long (SD=1.22). A one tailed paired t test was done comparing the length of uncoordinated and coordinated babbles. Results indicate that there is a significant difference between the length of uncoordinated babbles and the length of babbles coordinated with hand movements, $t(15)=2.13$, $p=0.003$. Similarly, there is a significant difference between the length of uncoordinated babbles and the length of babbles coordinated with leg movements, $t(15)=2.13$, $p=0.004$. No significant difference was found between the length of babbles coordinated with hand movement and the length of babbles coordinated with leg movement $t(15)=2.13$, $p=0.30$. Average babble length was not normally distributed and displayed a kurtosis of -1.78 for uncoordinated babbles, 4.50 for babbles coordinated with hand movement, and 1.33 for babbles coordinated with leg movement.

Babble diversity

The average diversity for uncoordinated babbles was 1.15 different syllables per babble (SD=1.25). The average diversity of babbles coordinated with hand movements was 2.06 different syllables per babble (SD=0.66). Finally, for babbles coordinated with leg movements they had an average diversity of 2.00 different syllables per babble (SD=0.93). Similarly to babble length, a significant difference was also found when looking at the diversity of coordinated babbles. A significant difference between the diversity of uncoordinated babbles and the diversity of babbles coordinated with hand movements was found, $t(15)=2.13$, $p=0.008$. Additionally, a significant difference between the diversity of uncoordinated babbles and the diversity of babbles coordinated with leg movements was also found, $t(15)=2.13$, $p=0.021$. In a similar fashion to the length of babbles, no significant difference was found between the diversity of babbles coordinated with hand movements and the diversity of babbles coordinated with leg movements, $t(15)=2.13$, $p=0.34$. Average babble diversity was not normally distributed and displayed a kurtosis of -1.45 for uncoordinated babbles, 6.44 for babbles coordinated with hand movement, and 1.41 for babbles coordinated with leg movement.

Type token ratio

The type token ratio, a ratio of the diversity over the length of a babble, of uncoordinated babbles was 0.40 (SD=0.43). The type token ratio of babbles coordinated with hand movements was 0.63 (SD=0.23). For babbles coordinated with leg movements they had a type token ratio of 0.67 (SD=0.23). Interestingly, only a marginal difference was found between the type token ratios of babbles. The difference between the type token ratio of uncoordinated babbles and the type token ratio of babbles coordinated with hand movements was found to be mildly significant, $t(15)=2.13$, $p=0.06$. No significant difference was found between the type token ratio of babbles coordinated with hand movements and the type token ratio of babbles coordinated with leg movements, $t(15)=2.13$, $p=0.64$. The difference between the type token ratio of uncoordinated babbles and the type token ratio of babbles coordinated with leg movement was also found to be very weakly significant, $t(15)=2.13$, $p=0.059$. Type token ratio was not normally distributed; kurtosis for uncoordinated babbles was -1.94, and 3.15 and 1.81 for babbles coordinated with hand and leg movement respectively.

Syllable Transitions

Our additional analysis focused on the location of syllable transitions. All babble transcripts were reviewed and any instances of a syllable transition were coded. In total there were 371 babbles that contained a syllable transition and 74 babbles that consisted of a single repeated syllable. Of the 371 babbles containing transitions, there were a total of 215 syllable transitions occurring at the centre of the produced babbles. Within babbles with centre transitions, 157 were coordinated with hand movements and 57 were coordinated with leg movement. Only 11 centre syllable transitions were uncoordinated with movement. Thus, approximately 73.02% of centre syllable transitions were coordinated with manual movement. Moreover, in total approximately 95% of centre syllable transitions were coordinated with some form of movement. Additionally, there were a total of 156 syllable transitions occurring at the edge of the produced babbles. 118 of the transitions were coordinated with hand movement and 27 were coordinated with leg movement. As with the centre syllable transitions, only 11 edge syllable transitions were uncoordinated with movement. Thus, approximately 75.64% of edge transitions were coordinated with manual movement and a total of approximately 92.95% of edge transitions were coordinated with movement. In summary, there were 371 babbles that contained some form of syllable transition. Of these 371 babbles, 349 were coordinated with either manual movement or movement involving the legs.

Through a one tailed paired t test we see a significant effect when comparing the number of centre transitions that are uncoordinated with movement and the centre transitions that are coordinated with hand movement, $t(15)=2.13$, $p<0.001$. When comparing the number of uncoordinated centre transitions with the number of centre transitions coordinated with leg movements we also see a significant result, $t(15)=2.13$, $p= 0.012$. When we compare the centre transitions coordinated with hand movement to the centre transitions coordinated with leg movement we also find a significant result, $t(15)=2.13$, $p<0.001$.

When we compare the uncoordinated edge transitions with the edge transitions coordinated with hand movement we also see a significant result, $t(15)=2.13$, $p<0.01$. Interestingly we do not observe a significant result when comparing the uncoordinated edge transitions and the edge transitions coordinated with leg movements, $t(15)=2.13$, $p=0.146$. When we compare the edge transitions coordinated with hand movements to the edge transitions coordinated with leg movements we do observe a significant effect, $t(15)=2.13$, $p=0.003$.

Finally, we looked at the babbles that did not contain any form of syllable transitions. 74 babbles in total did not have any form of syllable transition. Of these, 51 were coordinated with hand movements, 19 were coordinated with leg movements, and 3 were uncoordinated with any movement. We then compared the uncoordinated babbles with no transitions to the coordinated babbles with no transitions. When we compare the uncoordinated babbles with no transitions to the babbles with no transitions coordinated with hand movements, we see a significant effect, $t(15)=2.13$, $p=0.008$. A significant effect is also seen when comparing the babbles coordinated with hand movements that have no transitions to the babbles coordinated with leg movements that have no transitions, t (15)=2.13, p=0.006. Finally, a significant result is also found when we compare the uncoordinated babbles with no transitions to the babbles coordinated with leg movements that contain no syllable transitions, t (15)=2.13, p=0.046.

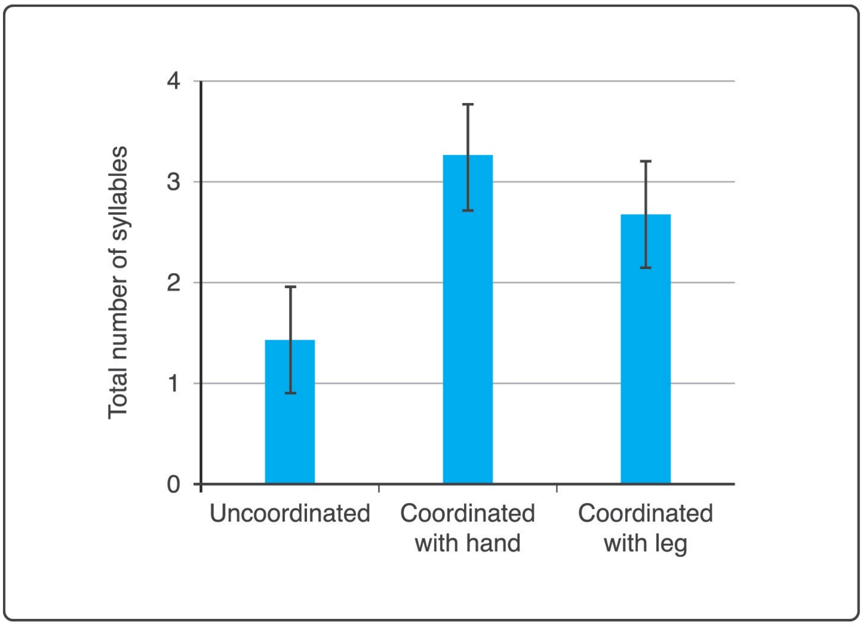
Laterality of movements

When we look at hand movements that are uncoordinated with babbles there was a total of 6062 hand movements produced. Once we remove the hand movements that are coordinated with babbles we are left with a total of 5748 uncoordinated hand movements produced by infants. Of these, 2299 were movements involving both hands, 2011 were right unimanual movements and 1438 were left unimanual movements. Thus, approximately 40% of uncoordinated movements produced by infants involved both hands. In contrast, approximately 35% of uncoordinated movements were right unimanual and 25% were left unimanual. So, although approximately 60% of uncoordinated movements involved a unimanual movement, only a very slight right hand preference is observed. Visual representation of the relative frequency of the laterality of movements uncoordinated with babbles can be seen in Table 1.1.

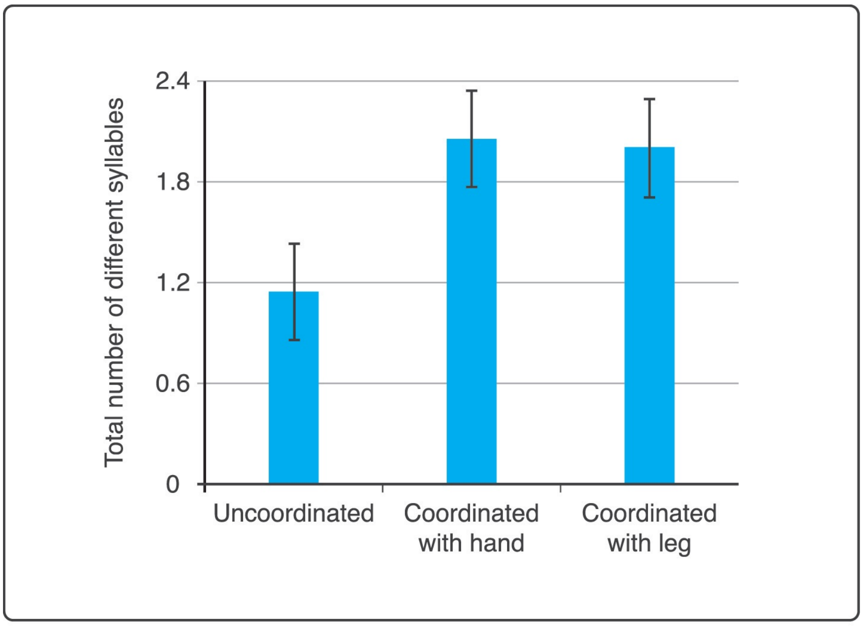
To continue, we examined whether infants displayed a right hand bias in coordinated manual movements. Of the 314 babbles coordinated with hand movements, 123 were performed unimanually with the right hand. In contrast, 95 involved left unimanual movements and 96 involved movements incorporating both hands. Thus, only 39% of babbles associated with hand movements involved a unimanual right hand movement, while 30% and 31% of movements involved only the left hand or both hands respectively. When we combine the rates of left and right hand unimanual coordination we observe that 69% of coordinated babbles involved unimanual movement. Visual representation of the relative frequency of the laterality of movements coordinated with babbles can be seen in Table 1.2.

Timing

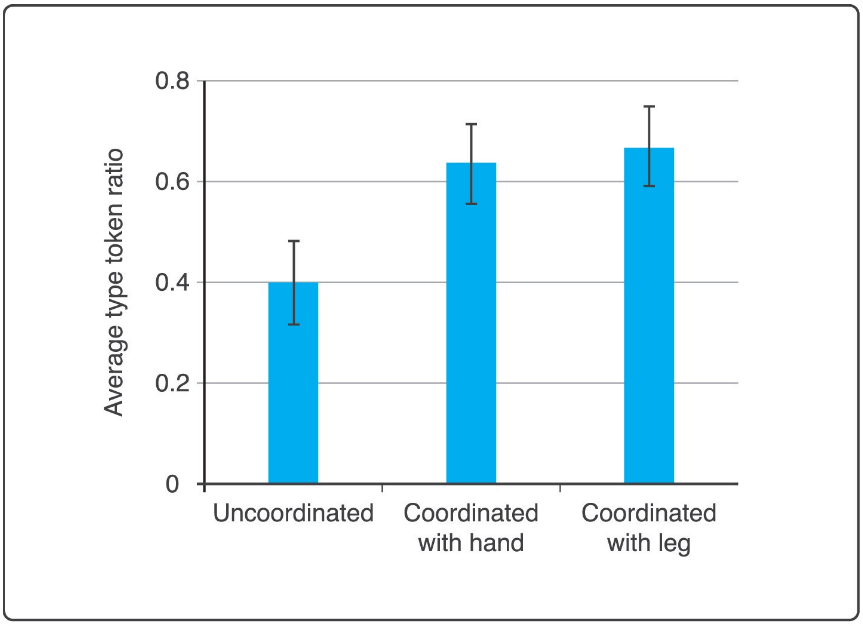
As the adult gesture system displays a distinct timing preference, wherein gestures appear in synchrony with or slightly prior to speech (Kimura, 1973a), our next set of analyses focused on the timing of our coordinated events. As mentioned previously, out of a total of 445 babbles, 419 were coordinated with movement. Of these, 276 were movement initiated whereby the movement made by the infant appeared slightly prior to their vocal output. 102 of the coordinated babbles were voice initiated, wherein the produced movements would appear slightly after the onset of babbling. Finally, 41 of the coordinated babbles were synchronous wherein the onset of movement and babbling appeared simultaneously. In other words, our results indicate that 66% of coordinated events were movement initiated. We also found that 24% of coordinated events were synchronous while only 10% were movement initiated. If we take into consideration the pattern observed in adult gesture-speech coordination wherein coordination between systems is most likely to be movement initiated or synchronous, we observe that 90% of the coordinated events produced by infants display this same pattern. The relative frequency for the timing of coordinated hand movements can be seen in Table 2.



Graph 1. Babble Length



Graph 2. Babble Diversity



Graph 3. Average Type Token Ratio

Hand Used	Frequency	Relative Frequency	Percentage
Right unimanual	2011	0.349860821	35%
Left unimanual	1438	0.250173974	25%
Both	2299	0.399965205	40%
Total	5748	1	100%

Table 1.1 Relative frequency of the laterality of uncoordinated movements

Hand Used	Frequency	Relative Frequency	Percentage
Right unimanual	123	0.391719745	39%
Left unimanual	95	0.302547771	30%
Both	96	0.305732484	31%
Total	314	1	100%

Table 1.2 Relative frequency of the laterality of coordinated movements

Timing	Frequency	Relative Frequency	Percentage
Movement initiated	276	0.658711217	66%
Voice Initiated	102	0.243436754	24%
Synchronous	41	0.097852029	10%
Total	419	1	100%

Table 2. Relative frequency of the timing of coordination

Discussion

In our study examining the effect of coordinated movement on infant vocalization, we compared the babbles produced by infants that were uncoordinated with movements with babbles that were produced in coordination with motor movement. We predicted that coordination between the systems would increase infants' vocal abilities, particularly in the form of babble length and complexity. Namely, we predicted that babbles that were coordinated with movement would be longer and have a higher number of different syllables than babbles produced without any form of coordination. Following this, we predicted that coordinated babbles would also have a higher type token ratio than uncoordinated babbles. In addition to length, diversity, and type token ratio, we also examined the location of syllable transition within the babbles, focusing specifically on centre and edge syllable transitions. Additionally, as coordination between motor and vocal outputs in infants has been suggested as a precursor to the adult gesture-speech system (Iverson et al., 2007), we aimed to investigate any similarities in laterality and timing between the observed coordinations produced by infants and the observed patterns in adults. Specifically, we examined whether infants displayed a right hand preference in movement and if coordinated events were movement initiated, synchronous, or voice initiated.

Experimental manipulation

Although we included an experimental manipulation of the addition of bells onto the limbs of the infants, no significant results were found as a result of said manipulation. While the infants were not distracted by the presence of bells, they also did not appear to increase their motor movement. Neither bells on their arms nor bells on their legs increased their motor output, suggesting that the addition of bells was not successful at encouraging babies to engage in motor movement of the limbs. This could be because the infants were already engaging in bouts of rigorous motor activity without the bells and thus the bells were an unnecessary addition. It could also be that the bells were not engaging enough to have an effect on motor activity.

Regardless of the condition, infants were found to engage in both babbling and motor movements fairly consistently. As hypothesized, babbles produced by infants were significantly more likely to occur with manual movements than with either leg movements or no movement at all. This result mirrors that of Iverson and Fagan (2004), which found that infants frequently coordinated vocalizations and manual movements. Both our results and those found by Iverson and Fagan (2004), mirror the adult gesture system in that speech is most likely to be paired with manual movements than with other forms of motor activity (McNeill, 1992).

Effect of movement on babble length

Our data also showed that babbles produced by infants were significantly longer when accompanied with motor movements than when they were produced alone. This effect was even more pronounced in the case of manual movements, the coordination of which saw the production of the longest stream of babbles. From this, we suggest that this result is evidence in support of the system of entrainment described by Iverson and Thelen (1999) that posits that activation from one system can leak into another coupled system. In the case of babbling, it may be that infants who are engaging in bouts of rigorous motor activity may be able to produce longer babbles as a result of the increase in activation. Comparatively, when infants engage in babbling without coordinated motor movement, the resulting babbles could be shorter as a result of a relative deficit in activation. We know that high levels of activation are seen in cases of well-practiced and familiar behaviours (Iverson & Thelen, 1999). According to Iverson and Thelen (1999) the effect of entrainment can only occur if there are high levels of activation in both systems. Thus we must conclude that in any observed instances of coordination between babbles and motor movements, the infants had high activation in both their motor and vocal systems. If the motor and vocal systems are as intrinsically linked as the current research would have us believe, then an increase in activation in the motor system leading to an increase in activation in the vocal system, and thus a longer vocal output, is completely plausible. In short, when infants are engaged in motor activity it appears as though it facilitates their ability to keep talking.

With that said, it is important to note that our experimental manipulation was ineffective at increasing movement output. As a result, we have no way of knowing for sure if the increase in babble length is directly caused by the coordination with movement. We must consider the possibility that any increase in babble length could be due to over excitation experienced by the infant.

Effect of movement on babble diversity

In addition to babble length, we also found that babbles produced by infants were more diverse when they were associated with movement. Specifically, babbles made while the infants were engaged in motor activity had a larger number of differing syllables than babbles that were uncoordinated with movement. This again could be the result of an increase in activation in the vocal system due to an increase in activation in the motor system. Forming a string of babbles with multiple syllables is a more challenging task than forming a repeated string of the same syllable. It then follows that babbles with higher syllable diversity require a higher level of activation in order to be properly produced. With the increased levels of activation resulting from the entrainment with the motor system, it may be that producing differing syllables becomes an easier task for the infants to undertake and they are better able to control their babbling.

It is important to note once again, that as our experimental manipulation was unsuccessful in directly manipulating the level of movement produced, we must be cognizant of the possibility that the increase in babble diversity is simply due to over excitation. Therefore, any proposed effects must be taken with caution, as the increase in diversity may be due to over excitation in the infant rather than a direct result of the coordination of movement.

Effect of movement on type token ratio

We must also highlight that we found only a mildly statistically significant type token ratio between the uncoordinated babbles and the babbles coordinated with movement. Specifically, the type token ratio of babbles coordinated with manual movements compared to the type token ratio of uncoordinated babbles was found to be significant. Additionally, the type token ratio of uncoordinated babbles when compared to the type token ratio of babbles coordinated with leg movements was also marginally significant. Although these results indicate that the coordination with movement may be resulting in more diverse babbles, a strong significant effect was not found. Accordingly, it may be that the observed increase in babble diversity might be due to the increased length of the babble. A longer babble is more likely to experience a change in syllable simply because it is longer and there are more opportunities for the infant to produce a differing syllable by chance. We therefore cannot confidently conclude that the coordination with motor movement had a direct effect on the syllable diversity produced by the infant, as it appears as though babble length may be too confounding of a factor to ignore.

Syllable transition location

Additionally, after analyzing the location of syllable transitions in the produced babbles, it became clear that the majority of syllable transitions, both at the centre and at the end of the babble, were coordinated with movement. Only 5.77% of babbles containing a syllable transition were uncoordinated with movement. This result suggests that the coordination of movement and babbling may have some effect on the infant's ability to precisely control their verbal output. Producing a syllable transition in the centre of a babble requires higher levels of verbal control than does the production of a syllable transition at the edge of the babble. Consequently, a higher level of activation is present in the babbles containing a centre syllable transition. It may be that increases in activation due to rigorous motor activity lead to entrainment of the vocal system, and consequently allow the infant to have more precise control over their verbal output. There is a comparatively similar link between systems in adults, which sees adults producing more gestures when engaging in more complex storytelling (Colletta et al 2010). This effect can also be seen in children, where their ability to engage in increasingly complex storytelling is also found to be paired with increases in gesture use (Colletta, Pelleng & Guidetti, 2010; see also Colletta, 2009).

That being said, we have no way of directly comparing our results with infants to the results from studies using adult or child populations due to the fact that the outputs are too dissimilar. While diversity and length of babbles share similar features to complexity and length of stories, they are evidently not on the same linguistic level. The increase in gesture use in the adult and child studies may be a result of increases in activation across the vocal and motor system, or may be explained from a linguistic point of view, such as an increase of gesture being required for an increase in the lexical access necessary to produce longer and more complicated stories. Nevertheless, it is interesting to note that an increase in gesture is associated with more complicated linguistic output across the developmental lifespan.

Laterality of hand movements

Our final area of analysis focused on direct comparisons between the patterns of infant vocal-motor coordination and the observed characteristics of the adult-gesture system. Specifically, adults' gestures consist almost exclusively of manual movements, with gesture rarely being seen through the use of the leg or other modalities. As we have mentioned previously, adults' gestures are most likely to consist of right unimanual movements than any other combination of movement (Kimura, 1973a; Kimura 1973b). This effect has also been observed in infants, with both Locke et al., (1995) and Iverson and Fagan (2004) reporting results indicating an observable right hand bias in infant motor movement. Ramsay (1984) suggested that a right hand bias found in infants around the time of babble onset is indicative of a shift in the hemispheric specialization of the brain. In contrast, our present study did not find any indication of a right hand preference. Although unimanual movements were more likely to occur than movements involving both hands, there was no evidence for a specifically right-handed tendency. This was seen in both the movements coordinated with babbles and the general movements produced by infants. Iverson et al., (2007) found a similar result in their study, where no right hand preference was observed in infant manual activity. Taken together, our results and those found by Iverson et al., (2007) suggest that the hemispheric specialization put forth by Ramsay (1984) may be a more ambiguous process than previously suggested.

Timing of coordination

Along with the laterality in movements, we also examined the timing of the vocal-motor coordinations produced by infants. In doing so, we see further parallels with the mature adult gesture-speech system. We found that coordinations were more likely to be movement initiated or synchronous with speech, while voice initiated coordinations were the least likely to be produced. Iverson and Fagan (2004) found a similar result, with movement initiated and synchronous coordinations appearing far more frequently than voice initiated coordinations. This is consistent to the pattern observed in adults wherein gestures are consistently produced just prior to or concurrently with speech (McNeill, 1992). This finding is also indicative of the potential direction within the systems in which entrainment may occur (Iverson & Thelen, 1999). As infants engage in rigorous motor activity just prior to, or at the exact onset of vocalization, we can suggest that the activation is moving from the direction of the motor system to the vocal system. Activation in the motor system appears to spill over into the vocal system, as suggested by Iverson and Thelen's model of entrainment, leading to a coordination and synchronization between the motor and vocal output (Iverson & Thelen, 1999).

Babbling as motor stereotypy vs. linguistic behaviour

As mentioned previously, some researchers believe that babbling is an inherently linguistic behaviour while others argue that babbling should be considered as an example of motor stereotypy. Given the results of our study, and similarly to Iverson et al., (2007), we maintain that the babbles produced by infants at this point in development should be considered as examples of mandibular oscillation. We do not deny the evidence suggesting that babbles are early linguistic events, but rather suggest that they begin as mandibullar oscillations, developing their linguistic components at a later stage in the developmental process (see also Iverson et al., 2007). As such, the babbling produced by infants can be considered as a rhythmic behaviour, with increasing control over the movement of the jaw and tongue resulting in more complex babbles. Bearing in mind the coupled system proposed by Iverson and Thelen (1999), entrainment between the motor and vocal systems leads to increases in activation, which in our study manifests itself as longer and more diverse babbles. Taking together the evidence of coupled systems, it is evident that there is a connection between the motor and vocal systems that begins at birth and continues to develop and become more precise across the lifespan.

The results of our study indicate that potential coupling between the vocal and motor system may serve to increase an infant's babbling capabilities. Moreover, it could be that babbles that begin as basic mandibular oscillations are able to transform to meaningful linguistic events due to the increased activation afforded to them by entrainment to the motor system. In order to develop mastery over a system, a high level of activation is required to increase the system's output. In the case of infant motor-vocal output, a simultaneously high level of activation in both the vocal and motor systems may increase an infant's ability to develop more thorough and precise control over both modalities.

Similar to Iverson and colleagues (2007), we suggest that researchers should not focus on whether babbling is either a motor skill or a language skill, but rather embrace the possibility that babbling may exist as both. Through mutual entrainment of the vocal and motor systems, infants are able to develop the physical mastery required to control the jaw and tongue movements that are necessary for effective speech. It is only after this level of mastery has been reached that babbles are able to begin to take on more significantly linguistic meaning. This increase in linguistic importance may be due to parent response as suggested by Iverson and colleagues (2007), or might be caused by some currently unknown developmental change. Regardless of the precise causes, it appears as though the coordination between babbles and motor movements is an important developmental milestone for infants.

Iverson et al., (2007) further suggest that the appearance of babbling is not just a motor and language milestone, but should also be considered as an important milestone in the development of the adult gesture-speech system. It could very well be that the motor and vocal oscillations made by infants directly transform into the complex vocal and gestural output produced by adults. That being said, as a result of the fact that adult gestures are tightly linked with speech, which is fundamentally linguistic, it is impossible to directly compare them with the observed motor and vocal connections in prelinguistic infants and such suggestions must be made with caution.

Limitations of the current study

Although we are able to make some propositions regarding the connections between systems, the lack of success with our experimental manipulation require us to do so with caution. Despite observed differences between the babbles produced in coordination with movement and the babbles produced alone, we cannot conclude that these differences were directly a result of the coordination of outputs. It could be that any observed differences were actually caused by over excitation experienced by the infant.

Additionally, the mildly significant result in the comparison of the type token ratios of the uncoordinated and coordinated babbles indicates that the potential linkages between babble and movement are not as straightforward as we may have hoped. There is insufficient evidence to say with confidence that activation in the motor system can lead to more complex vocal output. That being said, it does become clear that there are some profound connections between the motor and vocal system that can be seen from infancy. Both the increase in babble length as a factor of motor coordination, and the increased likelihood of the babble being coordinated with manual movement than other forms of motor movement or no movement whatsoever, indicates that there is some form of connection between the two systems that mirrors the adult gesture-speech system.

Due to the fact that this study had a small sample size (N=16) any suggestions for connections between systems should be considered with care. It could be that our results are due to the individual motor and vocal outputs of the infants included in the analysis and that a larger population would show different, and more reliable, effects. Additionally, babble rate varied considerably across participants included in the study. While some infants displayed high rates of babbling, others produced only a few babbles across conditions. With such a wide variety of vocal output across infants it is difficult to conclude that any observed effects apply to all infants included in the analysis. As a result, it is difficult to make confident conclusions that are applicable to the majority of infants. Additionally, given the confines of our study, our data set was limited to 35 minutes of observation per infant, which may be an insufficient amount of time to observe the individual infant's true babble rate. The presence of the researcher may have created a strange situation for the infant that unintentionally inhibited their vocal output. As such, the differences in babble rates across participations might have been minimized if the observed semi structured play sessions were longer and allowed the infant a more extended amount of time to become acclimatized to the situation.

Moreover, our study did not consider age as a factor in our analysis. Iverson and Fagan (2004) found an age related increase in motor movements while Ejiri and Mastaka (2001) found an age related decrease. As we were focused on the effect of movement on infant babbling, and all our infants included in analysis were classified as babblers, age was not considered as relevant. It could be that there is a specific age related factor in the coordination between the motor and vocal systems that is hidden within our results. However, as our sample size was small, if any age related differences were observed it would be difficult to determine if they were true age related differences or merely due to individual differences.

Finally, as with all infant research, differences in coding procedures also present a limitation to the study. Although we used a distinct coding procedure similar to that used by Iverson and Fagan (2004) there is room for researcher error and variability within coding (see also Nathani & Oller, 2001 for a review of the difficulties in coding infant verbal and motor output). Although we implemented strict coding procedures regarding the start and end points of both vocal and motor outputs, there is significant room for researcher interpretation when coding infant behaviour that must be taken into consideration when interpreting the results.

Directions for future research

Research continuing to explore coordination in the motor and vocal systems of infants should focus on avoiding the limitations exhibited in our current study, and continue expanding the current knowledge on infant vocalizations and movements and the potential overlap between the two. Ideally, future studies will include an experimental manipulation that is successful in increasing infant motor output. This will allow for more confident conclusions to be made regarding any observed differences between individual output and coordinated motor-vocal output.

Additionally, future studies should include a larger sample size, as this would allow the results to be more confidently generalized to a wider population. As infants are developing so rapidly there is a large amount of variability in their vocal and motor capabilities. A larger sample size would allow for a more accurate representation of infant motor and vocal output by reducing the possibility that the results found in this study were only applicable to the specific infants included in the analysis. What's more, future studies should collect a larger sample of data, allowing for a longer observational period for each infant and thus allowing the infants the opportunity to display a higher, and potentially more accurate, rate of babble.

Accordingly, a longitudinal study similar to that of Ejiri and Masataka (2001), would provide more comprehensive evidence as to the implications of potential overlap between the motor and vocal systems, as it would allow for the opportunity to observe the two systems at a variety of developmental points. Future studies should thus consider observing the infants before babble onset, around babble onset and after babble onset, similarly to that done by Iverson et al., (2007). This would allow for a more thorough observation of the rate of overlap between the vocal and motor systems. Moreover, it would allow for the observation of any differences in development that may be related to rates of coordination. For example, infants who display a high rate of vocal-motor coordination before or around babble onset may display differences in vocal output after babble onset than the infants who displayed a lower rate of coordination. Previous research has already found that gestures and gesture speech combinations tend to be correlated with total vocal production later on in development (Capirci et al., 1996). Additionally, gesture-speech combinations have been found to predict the onset of two word combinations (Butcher & Goldin-Meadow, 2000). Therefore, future research should include longitudinal data to further unpack the potential developmental consequences of high levels of infant coordination of the vocal-motor system. In short, to further understand the coordination between systems a larger amount of information covering a larger amount of the development is required.

Conclusions

Although there is still much to uncover about the intricacies of infant motor and vocal behaviour, this study offers some insight as to the relationship between the two systems. When coordinated with movement, babbles produced by infants are longer, more complex, and display a higher level of syllable transitions. What's more, the laterality and timing patterns observed in the infants' coordinated vocal-motor output is similar to that observed in adult gesture-speech production. Similarly to Iverson and Fagan (2004), we propose that the connections between the vocal and motor system in infants may serve as a precursor to the adult gesture-speech system. Just as gestures appear to play an important role in adult communication (McNeill, 1992; Iverson and Thelen, 1999; Krauss, 2001; Kita and Ozyurek, 2002; Alibali, Kita and Young, 2002) it appears as though motor movements have a paramount effect on infant vocal output.

Although there is much research involving vocal and motor coordination in adults, there are still a significant number of questions regarding the origins and implications of gesture in our communication and development. As Andrea de Jorio stated, "how little is known of the power of gestural expression, and how much more is there to observe" (de Jorio, 1832; translation from Kendon, 1997). With regards to gesture, there are many varied theories on their function and role in our communication. Most agree that gestures and speech are tightly timed, with gestures facilitating communication either through lexical access (Krauss et al., 2000), conceptual planning (Alibali et al., 2000) or imagistic thinking (McNeill, 1992). Regardless of the particulars of the theory, it becomes clear that gestures and speech form a tight system, the separation of which can often lead to dysfluencies in either or both systems (Butterworth & Hadar, 1989). In order to gain a more comprehensive understanding of the gesture-speech system, further research is needed to better understand the complexities of the rudimentary relationship between the vocal and motor systems. By beginning with research investigating the vocal and motor system in infants, we are able to gain a better understanding of the potential entrainment of the two and how they can develop into the complex and linked system observable in adult communication.

References

Alibali, M. W., Flevares, L. M., & Goldin-Meadow, S. (1997). Assessing knowledge conveyed in gesture: Do teachers have the upper hand?. *Journal of Educational Psychology*, *89*(1), 183.

Alibali, M. W., Kita, S., & Young, A. J. (2000). Gesture and the process of speech production: We think, therefore we gesture. *Language and cognitive processes*, *15*(6), 593-613.

Alibali, M. W., Heath, D. C., & Myers, H. J. (2001). Effects of visibility between speaker and listener on gesture production: Some gestures are meant to be seen. *Journal of Memory and Language*, *44*(2), 169-188.

Aziz-Zadeh, L., Wilson, S. M., Rizzolatti, G., & Iacoboni, M. (2006). Congruent embodied representations for visually presented actions and linguistic phrases describing actions. *Current biology*, *16*(18), 1818-1823.

Babkin, P. S. (1960). The establishment of reflex activity in early postnatal life. *The central nervous system and behavior*, 24-31.

Barzini, L. (1964). The *Italians* . London: Hamish Hamilton.

Bavelas, J. B., Chovil, N., Lawrie, D. A., & Wade, A. (1992). Interactive gestures. *Discourse processes*, *15*(4), 469-489.

Bavelas, J., Kenwood, C., Johnson, T., & Phillips, B. (2002). An experimental study of when and how speakers use gestures to communicate. *Gesture*, *2*(1), 1-17.

Beattie, G., & Shovelton, H. (1999). Do iconic hand gestures really contribute anything to the semantic information conveyed by speech? An experimental investigation. *Semiotica*, *123*(1-2), 1-30.

Butcher, C.M., & Goldin-Meadow, S. (2000). Gesture and the transition from one- to two- word speech: When hand and mouth come together. In D. McNeill (Ed.) *Language and gesture* (pp.235-257). Cambridge, England: Cambridge University Press.

Butterworth, B., & Hadar, U. (1989). Gesture, speech, and computational stages: a reply to McNeill.

Butterworth, G., & Hopkins, B. (1988). Hand-mouth coordination in the new-born baby. *British Journal of Developmental Psychology*, *6*(4), 303-314.

Capirci, O., Iverson, J. M., Pizzuto, E., & Volterra, V. (1996). Gestures and words during the transition to two-word speech. *Journal of Child language*, *23*(03), 645-673.

Church, R. B., & Goldin-Meadow, S. (1986). The mismatch between gesture and speech as an index of transitional knowledge. *Cognition*, *23*(1), 43-71.

Colletta, J. M. (2009). Comparative analysis of children's narratives at different ages: A multimodal approach. *Gesture*, *9*(1), 61-96.

Colletta, J. M., Pellenq, C., & Guidetti, M. (2010). Age-related changes in co-speech gesture and narrative: Evidence from French children and adults. *Speech Communication*, *52*(6), 565-576.

Davis, B. L., & MacNeilage, P. F. (1995). The articulatory basis of babbling. *Journal of Speech, Language, and Hearing Research*, *38*(6), 1199-1211.

De Boysson-Bardies, B. D., Sagart, L., & Durand, C. (1984). Discernible differences in the babbling of infants according to target language. *Journal of child language*, *11*(01), 1-15.

Ejiri, K., & Masataka, N. (2001). Co-occurences of preverbal vocal behavior and motor action in early infancy. *Developmental Science*, *4*(1), 40-48.

Erhard, P., Kato, T., Strupp, J. P., Andersen, P., Adriany, G., Strick, P. L., & Ugurbil, K. (1996). Functional mapping of motor in and near Broca's area. *Neuroimage*, *3*(3), S367.

Fagan M. K. Trends in mean length of utterance before words and grammar. University of Missouri; Columbia, MO: 2005. Unpublished doctoral dissertation.

Fenson, L., Dale, P. S., Reznick, J. S., Bates, E., Thal, D. J., Pethick, S. J., ... & Stiles, J. (1994). Variability in early communicative development. *Monographs of the society for research in child development*, i-185.

Fogel, A., & Hannan, T. E. (1985). Manual actions of nine-to fifteen-week-old human infants during face-to-face interaction with their mothers. *Child Development*, 1271-1279.

Gentilucci, M. (2003). Grasp observation influences speech production. *European Journal of Neuroscience*, *17*(1), 179-184.

Goldin-Meadow, S., & Singer, M. A. (2003). From children's hands to adults' ears: gesture's role in the learning process. *Developmental psychology*, *39*(3), 509.

Goldstein, M. H., & West, M. J. (1999). Consistent responses of human mothers to prelinguistic infants: the effect of prelinguistic repertoire size. *Journal of Comparative Psychology*, *113*(1), 52.

Graham, J. A., & Argyle, M. (1975). A cross-cultural study of the communication of extra-verbal meaning by gesture. *International Journal of Psychology*, *10*(1), 57-67.

Gullberg, M., De Bot, K., & Volterra, V. (2008). Gestures and some key issues in the study of language development. *Gesture*, *8*(2), 149-179.

Hill, E. L. (1998). A dyspraxic deficit in specific language impairment and developmental coordination disorder? Evidence from hand and arm movements. *Developmental Medicine & Child Neurology*, *40*(6), 388-395.

Hill, E. L. (2001). Non-specific nature of specific language impairment: a review of the literature with regard to concomitant motor impairments. *International Journal of Language & Communication Disorders*, *36*(2), 149-171.

Iverson, J. M., Capirci, O., & Caselli, M. C. (1994). From communication to language in two modalities. *Cognitive Development*, *9*(1), 23-43.

Iverson, J. M., & Goldin-Meadow, S. (1998). Why people gesture when they speak. *Nature*, *396*(6708), 228-228.

Iverson, J. M., & Thelen, E. (1999). Hand, mouth and brain. The dynamic emergence of speech and gesture. *Journal of Consciousness Studies*, *6*(11-12), 19-40.

Iverson, J. M., & Fagan, M. K. (2004). Infant vocal–motor coordination: precursor to the gesture–speech system?. *Child development*, *75*(4), 1053-1066.

Iverson, J. M., Hall, A. J., Nickel, L., & Wozniak, R. H. (2007). The relationship between reduplicated babble onset and laterality biases in infant rhythmic arm movements. *Brain and Language*, *101*(3), 198-207.

Kable, J. W., Kan, I. P., Wilson, A., Thompson-Schill, S. L., & Chatterjee, A. (2005). Conceptual representations of action in the lateral temporal cortex. *Cognitive Neuroscience, Journal of*, *17*(12), 1855-1870.

Kelly, S. D., Kravitz, C., & Hopkins, M. (2004). Neural correlates of bimodal speech and gesture comprehension. *Brain and language*, *89*(1), 253-260.

Kelly, S. D., Ward, S., Creigh, P., & Bartolotti, J. (2007). An intentional stance modulates the integration of gesture and speech during comprehension. *Brain and language*, *101*(3), 222-233.

Kendon, A. (1992). Some Recent Work from Italy on" Quotable Gestures (Emblems)". *Journal of Linguistic Anthropology*, 92-108.

Kent, R. D. (1984). Psychobiology of speech development: Coemergence of language and a movement system. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, *246*(6), R888-R894.

Kimura, D. (1973). Manual activity during speaking—I. Right-handers. *Neuropsychologia*, *11*(1), 45-50.

Kimura, D. (1973). Manual activity during speaking—II. Left-handers. *Neuropsychologia*, *11*(1), 51-55.

Kimura, D., & Archibald, Y. (1974). Motor functions of the left hemisphere. *Brain*, *97*(1), 337-350.

Kita, S., & Özyürek, A. (2003). What does cross-linguistic variation in semantic coordination of speech and gesture reveal?: Evidence for an interface representation of spatial thinking and speaking. *Journal of Memory and language*, *48*(1), 16-32.

Krams, M., Rushworth, M. F. S., Deiber, M. P., Frackowiak, R. S. J., & Passingham, R. E. (1998). The preparation, execution and suppression of copied movements in the human brain. *Experimental Brain Research*, *120*(3), 386-398.

Krauss, R. M., Morrel-Samuels, P., & Colasante, C. (1991). Do conversational hand gestures communicate?. *Journal of personality and social psychology*, *61*(5), 743.

Krauss, R. M., Dushay, R. A., Chen, Y., & Rauscher, F. (1995). The communicative value of conversational hand gesture. *Journal of experimental social psychology*, *31*(6), 533-552.

Krauss, R. M. (1998). Why do we gesture when we speak?. *Current Directions in Psychological Science*, 54-60.

Krauss, R. M., & Hadar, U. (1999). The role of speech-related arm/hand gestures in word retrieval. In R. Campbell & L. Messing (Eds.), Gesture, speech, and sign (pp. 93–116). Oxford: Oxford University Press.

Krauss, R. M., Chen, Y., & Gottesman, R. F. (2000). 13 Lexical gestures and lexical access: a process model. *Language and gesture*, *2*, 261.

Leiner, H. C., Leiner, A. L., & Dow, R. S. (1989). Reappraising the cerebellum: what does the hindbrain contribute to the forebrain?. *Behavioral Neuroscience*, *103*(5), 998.

Leiner, H. C., Leiner, A. L., & Dow, R. S. (1993). Cognitive and language functions of the human cerebellum. *Trends in neurosciences*, *16*(11), 444-447.

Locke, J. L., Bekken, K. E., Mcminnlarson, L., & Wein, D. (1995). Emergent control of manual and vocal-motor activity in relation to the development of speech. *Brain and Language*, *51*(3), 498-508.

Lynch, M. P., Oller, D. K., Steffens, M. L., & Levine, S. L. (1995). Onset of speech-like vocalizations in infants with Down syndrome. *American Journal on Mental Retardation*.

MacNeilage, P. F., & Davis, B. L. (1993). Motor explanations of babbling and early speech patterns. In *Developmental neurocognition: Speech and face processing in the first year of life* (pp. 341-352). Springer Netherlands.

MacNeilage, P. F., & Davis, B. L. (2000). On the origin of internal structure of word forms. *Science*, *288*(5465), 527-531.

Masataka, N. (2001). Why early linguistic milestones are delayed in children with Williams syndrome: late onset of hand banging as a possible rate–limiting constraint on the emergence of canonical babbling. *Developmental Science*, *4*(2), 158-164.

Mayberry, R. I., & Jaques, J. (2000). Gesture production during stuttered speech: insights into the nature of gesture-speech integration. *Language and gesture*, *2*, 199.

McNeill, D. (1992). *Hand and mind: What gestures reveal about thought*. University of Chicago Press.

McNeill, D., Cassell, J., & McCullough, K. E. (1994). Communicative effects of speech-mismatched gestures. *Research on language and social interaction*, *27*(3), 223-237.

McNeill, D., & Duncan, S. D. (1998). Growth points in thinking-for-speaking.

McNeill, D. (2000). *Language and gesture* (Vol. 2). Cambridge University Press.

McNeill, D. (2005). *Gesture and thought*. Chicago: University of Chicago Press.

Meier, R. P., & Willerman, R. (1995). Prelinguistic gesture in deaf and hearing infants. *Language, gesture, and space*, 391-409.

Meister, I. G., Boroojerdi, B., Foltys, H., Sparing, R., Huber, W., & Töpper, R. (2003). Motor cortex hand area and speech: implications for the development of language. *Neuropsychologia*, *41*(4), 401-406.

Nathani, S., & Oller, D.K. (2001). Beyond ba-ba and gu-gu: Challenges and strategies in coding infant vocalizations. *Behavior Research Methods, Instruments, and Computers, 33*, 321-330.

Nicoladis, E., Mayberry, R., & Genesee, F. (1999). Gesture and early bilingual development. Devel- opmental Psychology, 35, 514–526.

Nicoladis, E. (2007). The effect of bilingualism on the use of manual gestures. *Applied Psycholinguistics*, *28*(03), 441-454.

Ojemann, G. A. (1984). Common cortical and thalamic mechanisms for language and motor functions. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, *246*(6), R901-R903.

Oller, D.K. (1980). The emergence of speech sounds in infancy. In G.H. Yeni-Komshian, C.A. Ferguson, & J. Kavanaugh (Eds.), *Child phonology: Production* (Vol.1, pp. 93-112). New York: Academic Press.

Oller, D. K., & Eilers, R. E. (1988). The role of audition in infant babbling. *Child development*, 441-449.

Oller, D. K., Eilers, R. E., Neal, A. R., & Schwartz, H. K. (1999). Precursors to speech in infancy: The prediction of speech and language disorders. *Journal of communication disorders*, *32*(4), 223-245.

Oller, D. K. (2000). *The emergence of the speech capacity*. Psychology Press.

Özyürek, A. (2010). The role of iconic gestures in production and comprehension of language: evidence from brain and behavior. In *Gesture in Embodied Communication and Human-Computer Interaction* (pp. 1-10). Springer Berlin Heidelberg.

Pedelty, L. L. (1987). *Gesture in aphasia* (Doctoral dissertation, University of Chicago, Department of Behavioral Sciences, Committee on Cognition and Communication).

Petersen, S. E., Fox, P. T., Posner, M. I., Mintun, M., & Raichle, M. E. (1989). Positron emission tomographic studies of the processing of singe words. *Journal of Cognitive neuroscience*, *1*(2), 153-170.

Petitto, L. A., & Marentette, P. F. (1991). Babbling in the manual mode: Evidence for the ontogeny of language. *Science*, *251*(5000), 1493-1496.

Petitto, L. A., Holowka, S., Sergio, L. E., Levy, B., & Ostry, D. J. (2004). Baby hands that move to the rhythm of language: hearing babies acquiring sign languages babble silently on the hands. *Cognition*, *93*(1), 43-73.

Piaget, J. (1967). Logique et connaissance scientifique. *Paris: Gallimard*.

Pika, S., Nicoladis, E., & Marentette, P. F. (2006). A cross-cultural study on the use of gestures: Evidence for cross-linguistic transfer?. *Bilingualism: Language and Cognition*, *9*(03), 319-327.

Pulvermüller, F., Preissl, H., Lutzenberger, W., & Birbaumer, N. (1996). Brain rhythms of language: nouns versus verbs. *European Journal of Neuroscience*, *8*(5), 937-941.

Ramsay D.S. Onset of duplicated syllable babbling and unimanual handedness in infancy: Evidence for developmental change in hemispheric specialization? Developmental Psychology 1984;20(1):64– 71.

Rauscher, F. H., Krauss, R. M., & Chen, Y. (1996). Gesture, speech, and lexical access: The role of lexical movements in speech production. *Psychological Science*, *7*(4), 226-231.

Rizzolatti, G., & Craighero, L. (2004). The mirror-neuron system. *Annu. Rev. Neurosci.*, *27*, 169-192.

Rochat, P. (1989). Object manipulation and exploration in 2-to 5-month-old infants. *Developmental Psychology*, *25*(6), 871.

Seyal, M., Mull, B., Bhullar, N., Ahmad, T., & Gage, B. (1999). Anticipation and execution of a simple reading task enhance corticospinal excitability. *Clinical Neurophysiology*, *110*(3), 424-429.

Skipper, J. I., Goldin-Meadow, S., Nusbaum, H. C., & Small, S. L. (2007). Speech-associated gestures, Broca's area, and the human mirror system. *Brain and language*, *101*(3), 260-277.

Sundara, M., Namasivayam, A. K., & Chen, R. (2001). Observation–execution matching system for speech: a magnetic stimulation study. *Neuroreport*, *12*(7), 1341-1344.

Tettamanti, M., Buccino, G., Saccuman, M. C., Gallese, V., Danna, M., Scifo, P., ... & Perani, D. (2005). Listening to action-related sentences activates fronto-parietal motor circuits. *Journal of cognitive neuroscience*, *17*(2), 273-281.

Thelen, E. (1981). Rhythmical behavior in infancy: An ethological perspective. *Developmental psychology*, *17*(3), 237.

Vihman, M. M. (1996). *Phonological development: The origins of language in the child*. Blackwell Publishing.

Willems, R. M., & Hagoort, P. (2007). Neural evidence for the interplay between language, gesture, and action: A review. *Brain and language*, *101*(3), 278-289.

Wu, Y. C., & Coulson, S. (2005). Meaningful gestures: Electrophysiological indices of iconic gesture comprehension. *Psychophysiology*, *42*(6), 654-667.